AIR-AGE EDUCATION SERIES

THE BIOLOGY OF FLIGHT

FITZPATRICK-STILES

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EDUCATION SERIES

THE BIOLOGY OF FLIGHT

(A Text for High School Students)

BY

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FOREWORD

The revolutionary influence of aviation on military strategy is now recognized by laymen as well as by military authorities. It is also apparent that the influences of aviation on civilian life are equally revolutionary and perhaps more important from the long-term viewpoint. Wide seas, dangerous reefs, precipitous mountains, frozen wastes, and jungle depths, all barriers to earthbound generations, have become features of the landscape below the global sweep of the airplane travelers in the ocean of air which is now the third dimension for an air-free people. No aspect of human ecology will remain unaltered by this new instrumentality which not only abolishes distances but also reshapes basic human geography and remolds the internal and external relationships of national and continental population groups. City, state, national, and even continental boundaries vanish or become curious anachronisms to the stratospheric travelers on great-circle routes which wheel around a planet bereft of topographical restrictions.

Our educational leaders and the schools and colleges which they represent have made it clear that they will not only contribute directly to the paramount task of winning the war by helping to train the young men who will give air supremacy to the United Nations but will also help prepare the American people for constructive living as world citizens in the air age. The War Department, the Navy Department, the Civil Aeronautics Administration, the United States Office of Education, and state and local educators are advocates of this type of education.

The Air-Age Education Series represents a major step in providing our schools with teaching materials for these purposes.

This series has two objectives. First, it seeks to provide text and teaching materials for older students in high schools in the field of pre-flight aeronautics. Second, it seeks to provide pertinent aviation materials which may be woven into existing courses in the curricula of the secondary schools and, wherever feasible, of the elementary schools.

To name all the men, women, schools, aviation industries and authorities, publishers, representatives of colleges, universities, school systems, non-profit institutions and agencies of State and Federal Governments who made possible the Air-Age Education Series would be a difficult task. In individual books, authors have acknowledged assistance and advice from many sources. Yet the series owes its existence more particularly to a few individuals and organizations.

Special acknowledgments are due to Mr. Robert H. Hinckley, who, as Assistant Secretary of Commerce for Air, was the pioneer advocate of "air-conditioning" America; to Mr. C. I. Stanton, Administrator of the Civil Aeronautics Administration, who gave essential support to a program of aviation-education research; to Mr. Bruce Uthus of the Civil Aeronautics Administration, whose encouragement, resourcefulness, and ability so largely account for the development of the Air-Age Education Series; to Dr. John W. Studebaker, United States Commissioner of Education, who has done much to prepare American education to meet the challenge of the air age; to Professor N. L. Engelhardt, Teachers College, Columbia University, and his colleagues, who guided the development of materials reflected in this book and related teaching materials; and, finally, to Teachers College, Columbia University, for the provision of indispensable office space, library, and other research facilities.

The Institute of the Aeronautical Sciences, a non-profit scientific society devoted to the advancement of aeronautics, is glad to sponsor the Air-Age Education Series in the belief that it will aid American education to eliminate the hiatus between technical aeronautical advances and popular understanding of aviation as a revolutionary world force today and tomorrow.

BEN D. WOOD
Chairman, Education Committee,
The Institute of the Aeronautical Sciences

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LIVING THINGS IN THE AIR

WHEN the first living things took to the air there were no men present to note the event, for it happened long ages before our time. No doubt these pioneer plants and animals were tiny things that did not actually fly but were blown from place to place and from one level to another by the breezes. They must have had the atmosphere to themselves for millions of years.

The earth has always offered many kinds of habitats, or natural dwelling places, in which plants and animals can live. Related to their habitats are the several mediums in which such organisms can move about. We say that a fish is *aquatic* because it normally has its being in the water. The horse would be termed *terrestrial* because it walks or runs upon the surface of the earth. Earthworms and moles are said to be *subterranean* because they are usually found in the soil. Some kinds of monkeys, sloths, climbing reptiles, and other organisms are termed *arboreal* because they habitually dwell in the trees.

There is left one group of living things: those that can and do fly, either habitually or upon occasion. There actually are a good many of these, for the air is an ideal medium in which to move about. The fish is held back in its efforts to swim by the resistance of water, and digging through the soil is always a relatively slow process. Everyone knows that an automobile engine often has to work hard to pull the car up the hill. So, too, a person who is running must overcome the pull of gravity, the friction of contact with the ground, and the resistance furnished by the air. In flight or gliding, however, most of these difficulties are largely or wholly overcome, and the only important remaining forces are gravity and air resistance.

It is not surprising, then, to find that some organisms are able to fly rapidly and even to sustain themselves in the air for long periods of time. It is also noteworthy that they use the air as a means of escape from many natural enemies, and that they also employ it as a medium through which they can attack their prey. A hawk, for example, may soar over a meadow until it sees a field mouse or some other victim on the ground. Then it goes into a fast gliding dive, coming down upon its prey so rapidly and unexpectedly that there is little chance of its escape.

The Origin of Flight

Insects, the first fliers. Some of the awkward-looking insects that lived in Pennsylvania swamps millions of years ago probably were the first animals that could really fly. One type of insect, similar to our modern dragonflies, had a wing spread of nearly thirty inches. To such an insect, flight may have been a means of escaping from animals on the ground, but probably it also served the purpose of seeking food in the form of small prey. Primitive flying insects and their descendants lived on through one prehistoric era without any real competition in the air, but later, in the following, the Mesozoic, era all this was changed.

Winged reptiles. We are likely to remember the Mesozoic era as the time when the dinosaurs lived, but there were other animals of equal or even greater interest on the scene. One such group of animals was the pterodactyls or pterosaurs, which are sometimes called "winged reptiles." We know them only from fossils, for they have long since become extinct, but fortunately the record is fairly good. When they first came into being they were relatively small in size—some no larger than sparrows. They had leathery wings that went from the forelimb to the hind limb and the tail.[1] The little finger of a forelimb was greatly lengthened to support the front margin of a wing, and the other fingers were left free as claws. Some of these early pterodactyls had flukelike structures at the ends of their tails, which may have been used as rudders and balancing devices.

As time went on, the number of winged reptile species apparently became smaller, but the surviving types were more specialized and generally larger in size. One species is known to

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[1] The tail was long in some species and practically absent in others.

have had a wing spread of about twenty-five feet, although its body proper was only moderate in size. Moreover, it had hollow bones, which would again suggest light weight. On the other hand, there is little indication that any of the pterodactyls had unusually strong shoulder and breast muscles. All of this suggests that they undoubtedly could glide from an elevation to a lower altitude, and that some or all of them could soar, or rise to higher elevation, when they met with favorable air currents. The question as to whether they could sustain flight may never be answered.

The first birds. Let us now turn our attention to a group of Mesozoic animals that was destined to live on into the pres-

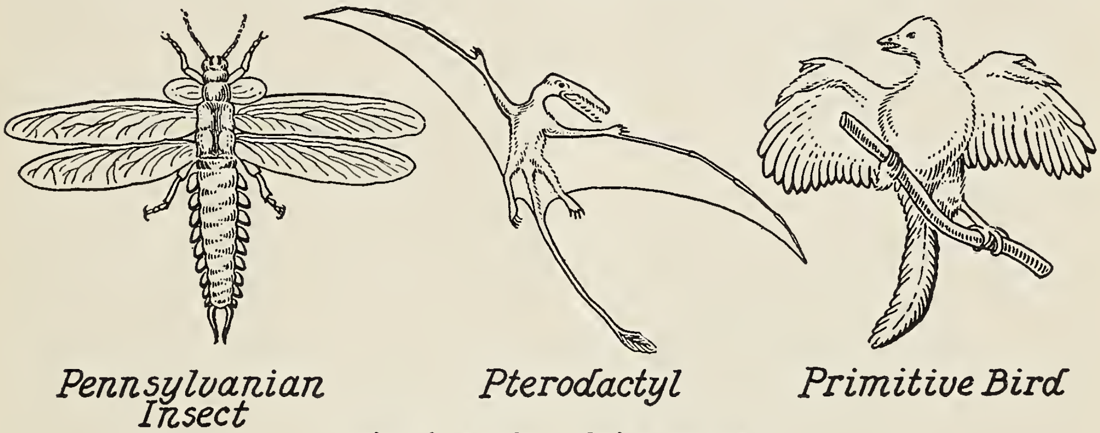

Fig. 1. Extinct flying types

ent. Some of the small reptiles probably had for centuries sought refuge in vegetation above the surface of the ground. One branch of this stock became possessed of feathers and in time developed into our modern birds. We know the "first" birds from fossils found in Bavaria. They appear to represent two different species that were quite similar in appearance. They were about the size of a modern crow and had feathers [2] on the wings, body, and tail.

Despite the feathers, these animals doubtless looked more like reptiles than like the birds that we know today. They had broad, blunt beaks, and both upper and lower jaws bore socketed teeth. Three digits of each forelimb remained free as claws. Their tails were rather long, fleshy processes, or projecting parts, bearing a row of feathers on each side. Foot bones were more like those of dinosaurs than are similar structures of modern birds.

[2] Feathers represent modified scales.

Various descendants of this or a related flying type, which were more birdlike in appearance, are known to have lived in the period following the Mesozoic era. This later period—the Cretaceous period—was also marked by the advent of flowering plants. Flowers, fruits, and seeds must have offered further reason for animals to be in the air.

Birds without teeth, as well as bats, make their fossil appearance early in the next era, the Cenozoic era. By the middle of this era the common flying types that we see today were well represented.

Various forms of aerial life, then, have been in existence for many, many years. There was therefore nothing new or startling about the fact that man finally conquered the air, although his method of conquering it was unique.

The Modern Air Population

To the person who does not know, the air about us today may seem to be largely free from living things except for occasional birds, bats, or insects. This is not really the case. During the past twenty years various collections have been made of the little plants and animals found in the atmosphere, and the results have been full of surprises. It is now known that the air is filled with all sorts of organisms, many of which are so tiny that they cannot be seen by the unaided eye.

Cysts, spores, bacteria, and pollens. Have you ever looked at a pond culture with the aid of a microscope? In the water one sees single-celled plants and animals, some of them swimming about actively. Now of course a good many ponds dry up during the hot weather of late summer. What happens to all of these tiny plants and animals of the unseen world when the water begins to evaporate? To be sure, some of them die, but many do not. A single animal cell, for example, may secrete about itself a little capsule called a cyst; plant cells do much the same thing. The cyst wall prevents too much loss of moisture, and the cell continues to live. Meanwhile, if the pond dries up completely, these tiny cells within their cysts may be picked up by the wind and carried into the air. They float about and sometimes get back into ponds or other bodies of water. When this happens the cysts dissolve and the cells take up active life again.

Many encysted organisms, however, are suspended in the air all the time, and so are the minutely small bacteria and the spores [3] of some bacteria, molds, rusts, and other plants. Certain fungi even have special structures for shooting their ripe spores upward and outward. Such facts explain why, if you take a few dry hay stems and put them in a jar of water, you sometimes

Acme Photo

Fig. 2. A man sneezing. This photograph was taken at ultraspeed.

get an active culture that contains bacteria, molds, and even tiny animals. It is also the reason why a moist piece of bread, left exposed to the air for two or three days, will almost certainly develop a growth of mold. Since the molds were not in the bread as it came from the oven, how did they get there? The explanation is that unseen mold spores float about us in our homes, offices, and schools. When they fall upon a suitable

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[3] A spore is a single cell capable of producing a new individual. Many of the simple plants produce such spores. A bacterium, for instance, which is itself only 1/25,000 inch in length, may divide to form hundreds of even smaller spores. Such tiny living particles may remain suspended in the air for long periods of time, although some of them are killed by the effects of sunlight and temperature.

object, such as a moist piece of bread, they soon give rise to mold plants if conditions of life are favorable.

As you probably know, the bacteria in the air may include types that we call germs or microbes because they can cause diseases. When you look at the picture of the person sneezing (see Figure 2) you can see how some of these germs come to be in the air. Their presence there has been of interest to students of health for many years. Since men have learned to fly they have become an even more important subject. You will learn more about them in Chapter 8.

Another group of things that float about are the pollens of many plants. They are said to have been found at an elevation of 16,000 feet; and pollens have been recovered from ocean air over the middle of the Atlantic, although they become rapidly less common as one proceeds away from the shore. The idea that pollens, bacteria, spores, and the like are carried along on or in particles of dust is only partly correct; as a matter of fact, they may themselves act as minute dust particles. Even bacteria that live in the sea get up into the air with droplets of water that are given off as spray when wave crests are swept by the wind or when waves break on reefs and roll up on coasts. Such droplets and the organisms in them may be carried to heights of several thousand feet.

The height to which some of these small plant cells may ascend is not known, but bacteria and mold spores have been secured by special balloon-transported devices at a height of 70,000 feet. Even so, their distribution by air seems to be limited in certain ways. Large natural barriers, such as deserts, mountains, and oceans, seem to hold them in check, at least in living form. Thus it was found that mountains (and other factors) prevented interchange of certain spores between northern and southern Mexico. We do not know nearly so much about the survival of microorganisms in the upper air as we might wish. Many of them are no doubt killed by the ultraviolet rays of light, low temperatures, velocity of movement, and desiccation; but certain types, notably bacteria, give evidence of being very resistant.

Seeds and fruits. While a good many of the simpler plants develop spores either habitually or occasionally, this is not true of some of the higher types of plants. You know that many land plants, such as trees, are rooted in the ground and cannot move about. In the spring of the year a maple may produce millions of seeds. If all of them sprouted in the shade of the parent tree, there would not be enough room for the new seedlings to grow and almost all of them would sooner or later die because of overcrowding. But this does not happen, because the air comes into the story.

The maple seed is really a fruit that contains a seed. This fruit is bladelike in form, and its center of gravity is at one end of the blade. Usually two fruits are developed together, with their bases, or heavier ends, attached. When a pair break from

Fig. 3. Two maple fruits; dandelion seed with air support; milkweed seed with air support

the tree they are caught by air currents and sometimes carried for great distances, meanwhile falling gradually, with a spinning motion (see Figure 3). The ash trees also develop "winged" fruits that are distributed in a similar way. The seed of a dandelion (see Figure 3) has a lightweight, feathery process attached to it; it may float for miles across the fields before finally coming to rest. Many seeds of weed pests are also transported by the wind.

Obviously men might have thought of wing support and parachutes from watching the fruits and seeds of certain plants. Probably this was not the case, however. It seems more likely that human efforts to fly were inspired by watching the birds. Nonetheless, we can learn a good deal from the study of plant structures that are carried by the air. We discover that the total weight must be relatively small, and that the "wing," or carrying surface, must be comparatively large. In the case of a maple fruit it is clear that a special type of motion in the air is achieved because the center of gravity is in a particular place.

Adaptations for Flight

Spores, cysts, and seeds floating about in the air are not really "flying." They show, however, that the air is full of living things, and that they can be supported by air provided that they meet certain structural requirements. When we consider the case of insects, however, we find many examples of true flight. Scientists have described and named almost a million species of these small animals. Some of them have no wings and cannot fly at all, but the majority have either two or four wings. Among them are types that fly remarkably well.

Fig. 4. A hawk moth

The insect body and wings. If you look at Figure 4, you will see that an insect's body is divided into three general regions: the head, the thorax, and the abdomen. The part that we are interested in at the moment is the thorax because it bears the legs and wings, which enable an insect to move about. The thorax is composed of three more or less fused segments, as can be seen if an insect is examined carefully. If only one pair of wings is present, they are borne on the middle and the last segments. Each wing has a bladelike surface supported by "veins." The veins themselves are surprising because they actually are modified respiratory, or breathing, tubes that grow out from the body in the process of development and become supports for the flight surface.

Notice that the wings have nothing to do with the legs. The latter are attached laterally on the lower side of the thorax. This arrangement is of course much different from that which we find in the case of birds or bats.

A hawk moth is striking because its body is so streamlined. Streamlining is evident also in the case of a dragonfly, as will be seen by reference to Figure 12. It is clear however, that the two types are quite different in body form, and therefore that effective streamlining can be attained in more than one way.

Insect skeletons. Another significant fact relates to the nature of an insect's skeleton. In general, a skeleton may serve three purposes: (1) to maintain the form of the body, (2) to protect some of the more delicate and vital structures within, and (3) to furnish places of attachment for muscles.

It is the last-named purpose that concerns us here. Without places of anchorage the muscles could not work effectively and flight would be impossible. In our own bodies the muscles that move the limbs, neck, and back are attached to a bony internal skeleton. In insects the corresponding arrangement is very different, for these little animals do not have much by way of internal skeletons.[4] Rather, they possess an outer covering of a hard but flexible material, called chitin; to this are attached the muscles that move the wings, legs, and some other parts. Apparently such an arrangement is effective in the case of small animals; in any event it serves to support the very high rate of muscular exertion that accompanies their flying movements.

Flight activities of insects. It should also be noted that many insects meet the requirements for flying organisms mentioned on page 7; namely, they are comparatively light in weight, and their flying structures furnish a large surface for support in the air. A further point of interest concerns the action of their wings, which, unlike those of birds and bats, are substantially rigid and cannot be altered in form to meet the varying conditions encountered in the air. Moreover, the second pair of wings in many species is folded beneath the first pair when the insect is at rest, and when two pairs of wings are present they may differ somewhat as to function.

Various kinds of flight are represented among insects, as described in Chapter 2. Their ability to move through the air enables insects to find food, to mate, to lay their eggs in suitable places,[5] and to do other things. In this connection the activities of some females remind one of the work done by a

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[4] There is no calcareous endoskeleton, but some chitinous elements are found within an insect's body.

[5] Many insects are noted for the fact that they deposit their eggs on or near suitable food plants or in places where such plants grew during the preceding season.

dive-bombing plane. The tachina fly that you see in Figure 5 serves as a good example. When the female is ready to lay an egg, she will fly over the fields searching for one of certain kinds of larvae.[6] Upon finding a desirable larva she will drop down and alight upon its back. There she may puncture the body wall of the larva with a special egg-laying device and deposit an egg in the larva's tissues, or in the case of other parasitic flies she may merely attach one or more eggs to the

Fig. 5. A tachina fly, with a larva that has been parasited by a tachina fly

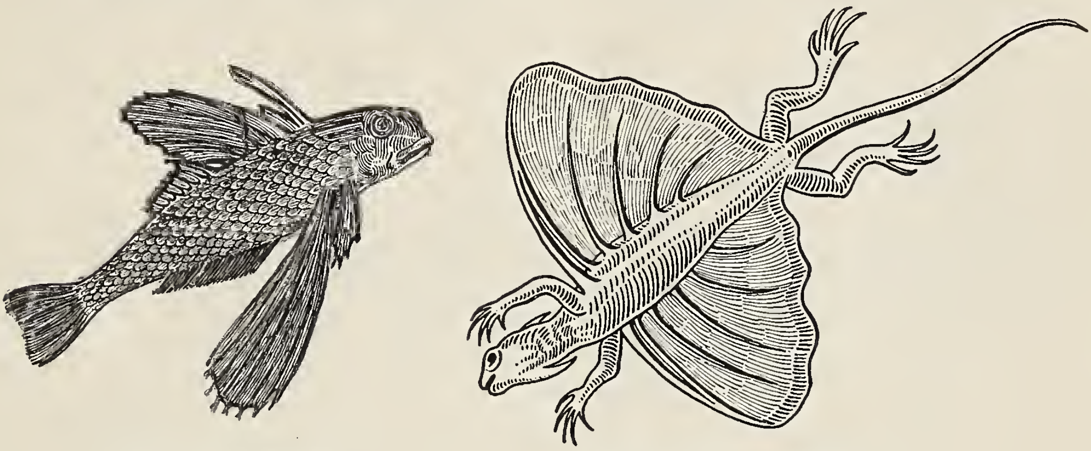
outside of the victim. What happens in either case is that the egg hatches, and that then the resulting young parasite proceeds to eat the larva that has been made the unwilling host.

Some insects fly high. The flight of insects is interesting in other ways. Some of them rise to great heights in the air. Collectors using airplanes have taken a variety of insect species at a height of 15,000 feet. At such an altitude, early studies showed, certain two-winged flies and various bugs were most common; but this may or may not be so, according to the locality and the time of year. Interestingly enough, even wingless insects are to be found in the upper air; obviously they have been picked up and carried along by rising air currents. Spiders (not insects, but arachnids) are also encountered, but

[6] Larvae are the wormlike young of some insects. Various kinds are known as grubs, maggots, caterpillars, and inchworms.

their presence is largely explained because they are riding their floating webs.

Flying fish. Among the fishes there are about seventy known species that engage in a sort of "flight." These are the so-called flying fish that are found in some of the warmer seas. Most of them are quite small; one of the larger types, the Atlantic flying fish, attains a length of about fifteen inches. The pectoral fins (see Figure 6) of these animals are unusually large and wing-like; and the pelvic fins, although smaller, provide some supporting surface. Flying fish will swim near the top of the water until they are moving rapidly. Then they will leap up into



Flying Fish *Flying Dragon*

Fig. 6

the air to plane along, sometimes for a considerable distance.[7] When they do this they look very much like a group of model airplanes, partly because the fins are not flapped but are held extended in a gliding position. The ability of flying fish to get up into the air is supposed to be of use to them inasmuch as they are thus able to escape some of their enemies in the water.

Flying dragons. Similar to the flying fishes are some twenty species of flying dragons, or flying lizards, which are native to the Malay and East Indian region. The large pterodactyls of the Mesozoic era became extinct by the end of that era, but these modern reptiles are capable of a gliding sort of flight. Their "wings," however, are very different from those of pterosaurs, birds, insects, or flying fishes. They are supported by long ribs,[8] which extend out from the body proper; stretched across

[7] It is said that they sometimes travel an eighth of a mile in the air.

[8] These are really the lower, or false, ribs, which are not attached to the sternum, or breastbone.

these supports are the two gliding membranes, one on each side of the body, as shown in Figure 6. When the animal is perched in a tree or bush, the "wings" fold to the sides of the body between the forelimbs and hind limbs, but they are spread to serve a glider function when the lizard leaps from branch to branch or from tree to tree. Flying dragons are of course incapable of sustained flight.

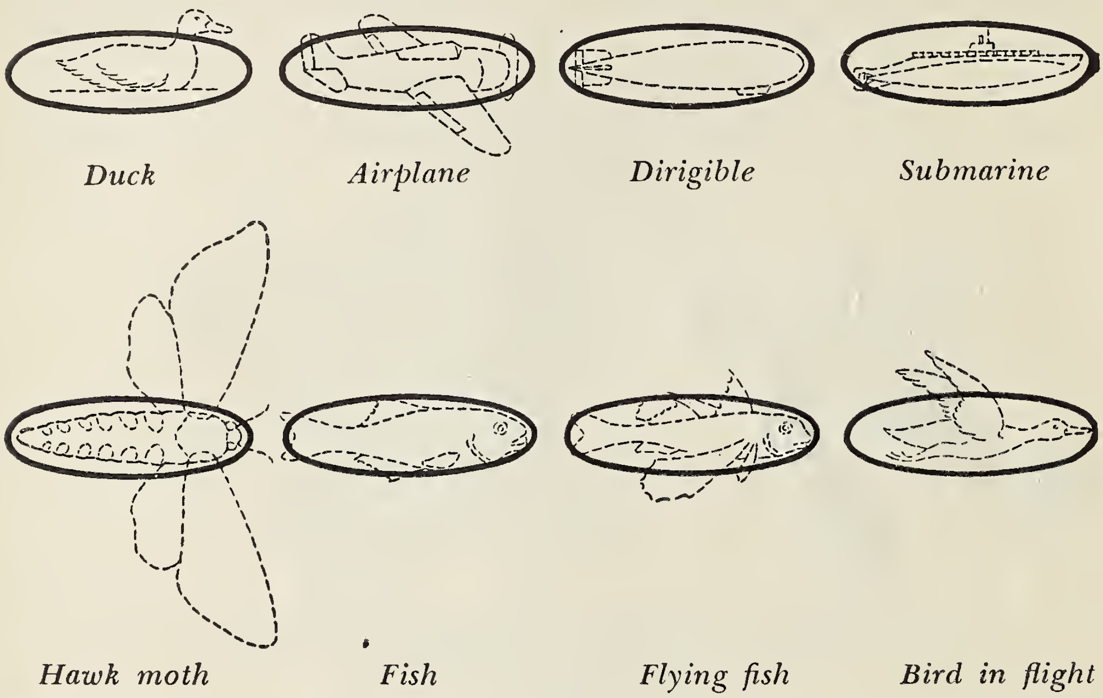


Fig. 7. Diagrams of living and nonliving things that have fusiform shape

Flightless birds. When most people think of flying animals their thoughts turn naturally to the birds. It is interesting therefore to observe that some species of birds cannot fly, and that a few are practically wingless. Most of the nonfliers have a rather difficult time in the modern world, and some of them have become extinct within the memory of man.[9] These facts suggest how important flight may be to animals, since it enables them to escape from many potential enemies, to migrate from place to place, and in some cases to obtain food while in the air.

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[9] Good examples are furnished by the now-extinct moas (New Zealand) and the elephant birds (Madagascar). These birds belonged to different orders, but both were flightless. Apparently their destruction was related to the fact that they were unable to escape from human enemies, who sought them for food. Surviving flightless types of birds include the kiwis, the Laysan rail, ostriches, cassowaries, emus, and penguins.

The fusiform shape. The majority of modern birds do fly, however, and the adaptations which make it possible for them to do so are interesting and significant. In the first place, there is the matter of body form. So much has been said and written in recent years about streamlining that almost everyone has come to know about air resistance. It is relatively hard to move a bulky and irregular object through the air; on the other hand, something that is *fusiform,* or tapering at each end, will meet with less resistance both in the air and in the water. The bodies of the average birds approach this shape, as do the bodies of most things that swim or really fly (study Figure 7).

Feathers. The flying surfaces of a bird are made up of feath-

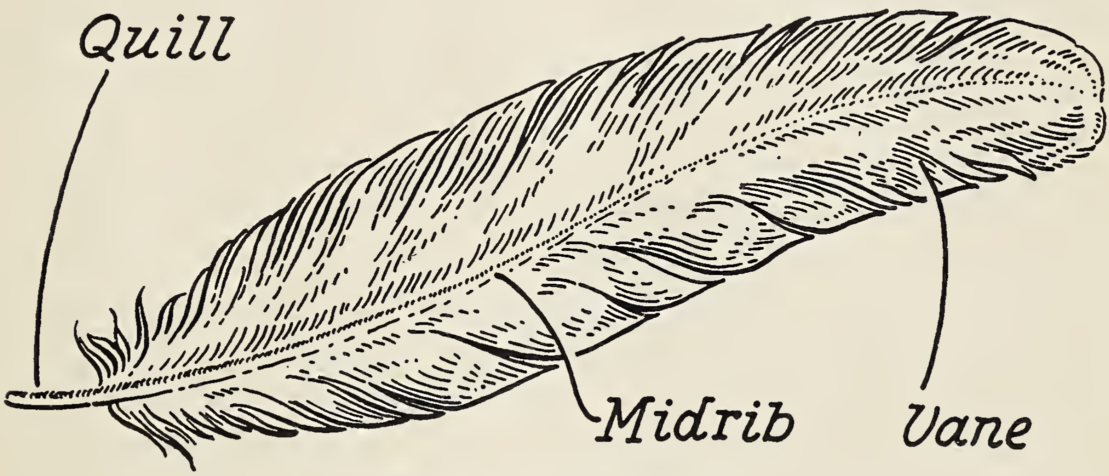

Fig. 8. A contour feather

ers. These structures are possessed by no other animals; and, as previously noted, they are really modified scales that have been handed down from the reptilian ancestors of modern birds. There are various kinds of feathers, ranging from tiny plumes and so-called down types to the larger, firmer contour feathers that more or less cover the outer surface. A contour feather, as shown in Figure 8, has a central support consisting of the quill and the rhachis. The vane is made up of an inner and outer web. Each vane consists of many barbs, which give off branches called barbules. The barbules bear smaller sub-branches, known as barbicels, and hooklets; and the entire structure is so interlocked as to be firm, yet yielding.

The principal flight feathers are borne on the wings and the tail. The wings, which are really modified front limbs covered with feathers, are the principal organs of support and forward motion in flight. They are not nearly so rigid as they might seem to be at first glance, and their shape can often be altered by the bird to meet varying demands of flight. The tail consists of a group of feathers attached to a bone in the rump area of the bird's body. Their positions are also subject to change, and tails are variously used as added flying supports, balancers, rudders, and brakes in landing.

Most birds molt, or shed their feathers, annually,[10] usually after the nesting season. This tends to assure that old, worn-out parts will be replaced.

The bird skeleton. The bird skeleton reveals amazingly appropriate adaptations for flight, of which only the more important ones will be mentioned here. In the first place, the long bones are generally hollow, and this means lighter body weight. Also the bones of the shoulder girdle provide unusually good support for the wings.

As you may know, the human shoulder girdle on each side of the body consists of a collar bone (clavicle), which extends from the upper end of the breastbone (sternum) to the point of the shoulder. At the latter location it meets the shoulder bone (scapula), which extends down into the muscles of the back. The bone of the upper arm (humerus) is attached where the collar bone and the shoulder bone come together. This arrangement provides a rather insecure support for the arms, as indicated by the fact that shoulders frequently become dislocated and collar bones broken.

A bird has both a collar bone and a shoulder bone (on each side of the body) which correspond to those of man. The bird's shoulder bone, however, is not loosely inserted among the muscles of the back but is bound to the ribs and the vertebral column by ligaments. Moreover, there is a third bone in the shoulder girdle (on each side of the body), which gives added powerful support for the shoulder point. This bone is the coracoid, which extends from the shoulder downward and backward to connect with the sternum. It is another structure that birds owe to their reptilian origin.

The bird's sternum itself is also worthy of special note. In

[10] Some species molt twice a year.

types having good powers of flight[11] we find that this breastbone bears an extensive keel, a flat, bladelike process set in the vertical plane. The heavy breast muscles of a bird, which really are the principal muscles used in flying, extend down from the shoulder region and are fastened to this keel. We have already suggested that secure attachment of muscles is necessary if they are to perform their functions well.

A further characteristic of the bird skeleton is that many of the bony parts are fused, or grown together. The skull, for example, instead of being a mass of small, distinct bones, is largely joined together in one piece except for the lower jaw. Similarly the vertebrae of the backbone (thoracic vertebrae) are usually fused, and so are various elements of the leg and wing bones. On the whole, the great reduction in the number of free parts makes possible considerably lessened weight without any great sacrifice of strength or protective value. The general stiffening of the back region (fusion of thoracic vertebrae) also seems to be related to the function of flight.[12] The entire setup of backbone, ribs, sternum, and shoulder girdles is, in fact, one which gives unusually good support for the wings.

Respiration of birds. From other studies you have learned that, after food materials have been assimilated by cells, they can be oxidized[13] so as to liberate energy for work. To this end there must be a steady and dependable supply of oxygen, and this is where the respiratory system comes into the picture. In a bird this system is different from that of any other type of animal. Air may be taken in either through the nostrils or through the mouth, as in the case of man, and it then goes to two compact but efficient lungs.

A bird, however, has other air spaces, including air sacs, and hollow passages of the long bones, into which air sacs may ex-

[11] It is perhaps significant that flightless birds, with a few exceptions, have very poorly developed keels. The exceptions concern special cases, such as the penguins, which use their rudimentary wings extensively in swimming.

[12] Among other things, it enables the bird to overcome wind resistance with greater ease. Flexibility is retained, because the neck vertebrae are freely movable and because the position of the tail feathers can be altered at will.

[13] Actually of course it is the protoplasm of the cell that is oxidized, once assimilation has taken place. This protoplasm must be built up again by the further incorporation of food materials.

tend. A bird's air sacs lie within the body and communicate with the air passages of the lungs. One of them [14] extends laterally into the hollow bones of the forelimbs; and in some species, such as albatrosses, most of the long bones contain parts of air sacs. Since such cavities do not have any great number of blood vessels in their walls, we may assume that little exchange of gases takes place in these centers. They are, however, capable of holding a considerable amount of air, which probably can be used to advantage by swimming and diving birds.[15]

A further function is that internal perspiration takes place in air sacs. This permits regulation of a bird's temperature. In addition, it may be noted that, when a bird inhales, lungs and air sacs are filled. Then, when air is forced out of the lungs, relatively fresh air enters them from the air sacs. Thus the efficiency of the lungs tends to be increased over what it would be if no air sacs were present.[16]

Birds and men. All of these special bird adaptations and others discussed in Chapter 2 indicate that a bird's skeleton, muscles, and breathing apparatus are particularly well suited to the activity of flying. Comparison of the bird's body with that of man shows why it is not practicable for a man to tie on a pair of artificial wings and use his arm muscles to fly or glide. Some of the early experimenters tried to do this, but they soon found that they did not possess the necessary physical equipment. Man's skeleton, his muscles, and his rate of metabolism are not prepared to support this type of effort.

Flying squirrels. Among the mammals that fly are the flying squirrels, which are well represented in some timbered areas of North America. These little rodents are not fliers in the true sense of the word, but they can and do glide in going from one tree to another or to the ground. It is claimed, in fact, that some of them can thus traverse fifty yards or more. Their special adaptation consists of a lateral skin fold on each side of the body, which extends from forelimb to hind limb. The gliding surface differs in nature and origin from that possessed by flying

[14] The interclavicular air sac.

[15] Loons and grebes, for instance, since they are celebrated for their diving ability and can remain under water for remarkably long periods of time in view of the fact that they are warm-blooded.

[16] Authorities are not in full agreement as to the probable importance of these air sacs insofar as the efficiency of respiration is concerned.

fishes and flying dragons, but the type of "flight" involved is about the same. Flying squirrels are also able to use their flat tails as steering structures in the air.

Bats. The really efficient fliers of the mammal group are the bats, of which there are about 600 known species. Their so-called wings are also lateral extensions of the skin layers. The wing is stretched between the last four digits of the front limb (see Figure 9); then it extends back and is attached to the hind limb and finally to the tail, where it meets with the wing from

Flying Squirrel *Bat*

Fig. 9

the other side of the body. The supporting surface thus provided is rather large. In one species of flying fox [17] the wing expanse is about five feet, compared with a body length of one foot.

The metabolism of bats probably does not equal that of birds in efficiency (see page 21), nor are bats capable of the sustained flights performed by some birds. Bats do have one superior ability, however, which is represented by marvelously good co-ordination in flight, which is similar to "good timing" in sports—for example, when a batter hits the ball squarely.

You may have seen bats zigzagging through irregular spaces among the branches of trees and marveled at the ease with which they were doing so. It appears that the explanation may involve more than one thing. To begin with, bats can of course see where they are going, but they also undoubtedly depend upon other senses than sight. Blindfolded bats, for instance, have been turned loose in rooms across which strings were stretched at various angles. The bats flew about, for the most part without striking anything. It has been claimed that they

[17] The so-called flying foxes are certain Oriental, African, and Asiatic species of bats.

are able to "feel" the near approach of a solid object because of air compression. Another possibility is that they emit sounds too high-pitched for the human ear to detect, and that reflection of the sound waves indicates the presence of solid objects. They also clearly have great ability to change direction abruptly while in flight; in other words, they have "split-second" co-ordination.

Summary

There are many organisms in the air. We have seen that the air has a large population of both plants and animals, and that in it are other structures, such as the pollens, seeds, and fruits of certain plants. This great aggregate of flying and floating organisms is likely to be most extensive during hot, dry weather for obvious reasons. Some of the things in the air travel, or are carried, for great distances, including not only the strong fliers but also plants and animals that cannot fly at all.

The study of organisms that live in the air is now known as *aerobiology.* It is a rapidly growing science, one that promises to yield many worth-while facts. We know that some living things are found at an altitude of over ten miles, and many different types of living things have been collected by airplane at heights of three to five miles. It is also clear that certain living things encounter physical hazards to life, such as the ultraviolet rays of light and subzero temperatures; yet many of them manage to survive. Included among the members of the air population are bacteria and spores, some of which are the known causes of important plant diseases. Others, particularly some of the cocci, may have relationships to human diseases (see Chapter 8).

Adaptations for flight. Adaptations for flight range from mere small size and light weight to some of the special structures exhibited by insects, birds, and bats. The great majority of organisms found in the air are there largely or wholly because they are carried and supported by air movements or currents. Flying fishes, flying dragons, and flying squirrels are confined to the air near the earth's surface; they are examples of animals that glide but do not fly. It has been noted that their supporting structures serve the same general purpose but are actually developed in quite different ways.

Among the insects, birds, and bats are species capable of true, sustained flight, whether aided by rising currents or not. The flying structures of these three types vary, one from another. Wings of insects are quite independent of their legs, while those of birds represent modified front limbs, and flying membranes of bats involve both forelimbs and hind limbs, not to mention the tail. The material of an insect wing is chitin, the feathers of birds are modified scales, and bats develop lateral extensions of the skin layers. There is one common ground, however, in that supporting structures (wings) are present, and that their surface area is comparatively large in terms of the weight to be lifted.

Previously it has been suggested that ability to fly depends not alone upon the possession of wings, or carrying surfaces. Such structural adaptations must, for one thing, be supplemented by a metabolism that will support the necessary muscular activity, a topic that is further discussed in Chapter 2. For effective flight there must also be a superior ability to co-ordinate, which means an efficient working together of the muscular and nervous systems. All of these requirements are met to a greater or lesser extent in the animals that fly. Bird movements are well-co-ordinated, but it is doubtful if they match the marvelous exhibitions of bats.

This brings the story to the case of man himself. The first point we may note is that the human skeleton, muscles, and internal organs are not primarily adapted for flight after the manner of birds or bats. Man, however, does have one capacity vastly superior to that of any other flying organism; this of course is his intelligence, which has enabled him to obtain mastery over his environment by building balloons, gliders, and airplanes. Given a suitable machine, man with his powers of co-ordination is equal to the task of making it perform like the birds and even surpassing them in some particulars.

2

THE NATURE OF FLIGHT

THE ability to fly has given several groups of animals certain advantages. They have been enabled to seek food and water over wide areas, to escape from many of their enemies, and even to migrate long distances. Birds, bats, and insects are all found in widely separated parts of the world, and this is so partly because they are able to use the air in moving from place to place and to cross natural barriers that would halt their earth-bound associates. One may note that the new ability of man to fly has had something of the same result. Distances are no longer great obstacles to travel, and to all intents and purposes the world has become much smaller.

The vast air population described in Chapter 1 may be roughly divided into two groups of organisms. One of these is made up of living things that float along with air currents, or glide, or are capable of only feeble flight. They are more or less at the mercy of the winds. The other group includes some insects, some birds, and the bats, which are capable of true, *sustained* flight. It is with this second type that we shall be primarily concerned in the present discussion.

Energy and Flight

Energy for flight. As you would expect, sustained flight often calls for the use of considerable energy, especially if the wings are flapped all the time. This means that a steady stream of energy must be supplied from some source. In the case of an airplane an engine is the source, and oxidation of gasoline releases the necessary energy. The same general result is effectd in an animal's body when the substance of a muscle cell is oxidized; in this process energy is again made available, and the muscle cell is thus able to contract. The systems that supply needed materials in the case of a bird or mammal are the respiratory system (oxygen) and the digestive system (foods). The circulatory system acts to carry these necessities and also to remove the wastes that are finally cast off by the excretory organs.

Insect metabolism. In the case of insects the story of energy use is complicated by a number of factors. In the first place, some adult insects take food and others do not. Those that go without must depend upon stored materials that have been carried over from the time when they were larvae.[1] Their respiratory structures are also unusual, being made up of a system of tubes (tracheae) and their smaller branches, which reach all parts of the body. The main tubes connect with openings (spiracles) on the lower sides of the body. The circulatory system does not have to act as an oxygen carrier, because all tissues of the body are reached directly by tracheae and their branches. An insect, moreover, is cold-blooded, and thus its basic rate of metabolism depends to a large extent upon what outside temperatures happen to be.

Bird metabolism. Birds, on the other hand, are warm-blooded, and their basic rate of metabolism is high whether the weather is warm or cold. Such rapid metabolism depends partly upon the fact that their digestive systems are efficient and are capable of supplying the blood stream with large amounts of digested foods. A bird may fill its crop[2] or its stomach several times a day if enough food can be found. Digestion is quite rapid, and so is the disposal of wastes. The circulatory system also is highly efficient, probably even more so than that of man. Normal body temperatures of a bird range from about 100° F. to over 112° F. in various species and at different times.[3] The

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[1] Many (but not all) strong fliers among insects pass through what is known as complete metamorphosis. In this type of development the life cycle is represented by four clearly marked stages: the egg, the larva, the pupa, and the adult. Eating often is the principal activity during the larval stage.

[2] Certain birds, such as domestic chickens, develop a crop as a special part of the esophagus, which acts as a temporary storage place for food. In some species the stomach consists of two parts: the first of these is the proventriculus, which receives the food, and the second is the ventriculus, or gizzard. In other birds, the stomach is just a simple sac.

[3] This high body temperature indicates a rapid rate of metabolism. In a warm-blooded animal, such as a bird, body temperature does not remain constant in normal health but moves through a more or less regular daily cycle of change.

system of arteries and veins is finely branched and reaches the body tissues in a rather thorough manner. Supposedly therefore oxygen and absorbed food materials are supplied to the cells of the body with a minimum loss of time.

All of the foregoing facts point to a rapid rate of energy use; and, when we recall the special adaptations of birds that are discussed in Chapter 1, it is easy to see why strong fliers are to be found among them. Clearly they exhibit better all-around adaptation for flying than is shown by either insects or bats. Even the best insect flier, for instance, is at the mercy of cold weather. In general, flight structures show great variation among different organisms, so that good ability to fly does not depend upon any one function but rather upon a variety of factors.

Types of Flight

Some definitions. We now come to the subject of how flying structures are used by birds and other animals. For the sake of clarity, let us begin by defining terms used in describing different kinds of flight. Some earlier statements have been made about *gliding*, which means holding the wings in a more or less fixed position and moving smoothly and gently—volplaning—through the air, usually but not always with loss of altitude.[4] *Soaring* implies gliding upward[5] by virtue of any velocity the moving body may have, sometimes with the aid of favorable air currents. *Sailing* is a combination of soaring and gliding, whereby a bird maintains altitude and even moves from place to place with little or no visible wing movement. *Flapping flight* is the normal type of flying, in which support and forward movement depend upon a beating of the wings. However, these terms, you will find, are not always used with the same meanings.

Gliding flight. We have seen that for flight some animals can only glide. Many species, including birds and insects that fly well, however, make gliding a part of their performance. Thus a hawk or a pigeon may set its wings and glide down to a lower elevation, sometimes for the purpose of alighting in a

[4] If they have sufficient momentum, various insects and birds are able to glide horizontally, at least for a limited distance.

[5] The wings are also in a set, or fixed, position during the act of soaring.

tree or on the ground. When you walk through a field you may scare up a grasshopper that has been sitting on the ground or a plant. Its powerful hind legs are used to leap into the air. Then it may use its wings for a few moments in moving away from you, but finally it glides down to another hiding place in the grass. Or watch a flock of ducks alight on the water. They may circle above a pond with their wings beating rapidly, but when they have picked out a suitable spot they often turn into the wind and go into a long glide as would a seaplane that is about to alight. This slows their flying speed, and they strike the water while going almost parallel to its surface. After they have coasted over the water for a short distance their forward motion is checked, and they come to rest with what might be called perfect landings.

As previously noted, a pigeon may use a glide in coming down to the ground, but there is at least one difference. The pigeon does not strike the ground while it still has forward motion. Rather, when a few feet or inches above the surface it beats its wings in such a way as to oppose such motion and comes to what is practically a dead stop in the air before its feet touch the ground. More or less the same thing is done by many birds that alight upon solid objects.[6] We may note that birds, insects, and other flying types encounter the same problem that is faced by aviators in coming down out of the air. They must have some way to check forward motion and to render it harmless.

There is obviously some advantage in being able to glide, as we see from these facts about the ways in which birds come down to rest upon ground or water. But there are other advantages, as, for example, in the fast dive of a hawk that is descending upon a victim. In this case the dive is a glide that may become almost vertical. It is also noteworthy that gliding tends to conserve energy, which would be used much more rapidly if the wings were in constant motion.

Soaring. According to our definition, soaring is similar to gliding, except that in the case of soaring the bird moves upward. At the end of a downward glide, for example, a hawk, a vulture, or a gull may change the positions of its wings and tail

[6] Even some ducks and other water birds can and do use this technique upon occasion.

so as to turn upward. In this case the necessary lifting force is in part supplied by the momentum of the preceding glide. It is not uncommon, however, to see hawks and similar birds soar upward out of a horizontal glide without having flapped their wings. Part of the explanation may be that they take advantage of rising currents of air or of air masses moving at different speeds. Thus they will glide down wind and then turn into the wind and take advantage of its lifting power.

Many birds glide to a greater or lesser extent, but those that soar effectively are a smaller and more select group. To soar, it seems almost necessary that the carrying surfaces of wings and tail be unusually large in terms of the weight to be lifted. Like gliding, soaring is an energy-conserving process. Some birds gain altitude only because they use their wings actively; others are able to take advantage of momentum and air currents.

Sailing. The layman is inclined to say that a vulture or a hawk "soars" in the sky. Strictly speaking, however, this is only part of the story, for what the birds actually do is to sail—a combination of gliding and soaring. In this sailing process a vulture may continue in the air for hours without flapping its wings. Nonetheless, it maintains its altitude and moves across country. At sea an albatross may circle about a ship and follow along with it in much the same manner.

We often see hawks and eagles sailing above the border of a forest, the side of a mountain, or along a range of hills. Probably you have learned that there are likely to be rising currents of warm air in such places, and that these may be used to some extent by the birds. Similarly a gull which is crossing the coast line may gain altitude by using upward currents of air that have been deflected by cliffs. This is very much like what is done by a skillful glider pilot who follows along a range of hills or mountains, taking advantage of any upward air movements to gain greater height. The performance of a glider, in fact, resembles the act of sailing, and for this reason gliders are often called sailplanes.

It is also thought that the real secret of sailing flight depends upon a bird's ability to take advantage of varying velocities of air at different levels (see page 22), and that the use of updrafts of warm air will not explain the fact that sailing birds are often able to move freely in a horizontal plane. There is also the observed fact that they move various parts of the body and certain feathers, apparently in such a way as to take best advantage of any air currents. For example, the feathers at the wing tips of an eagle when sailing are spread and curved upward at the

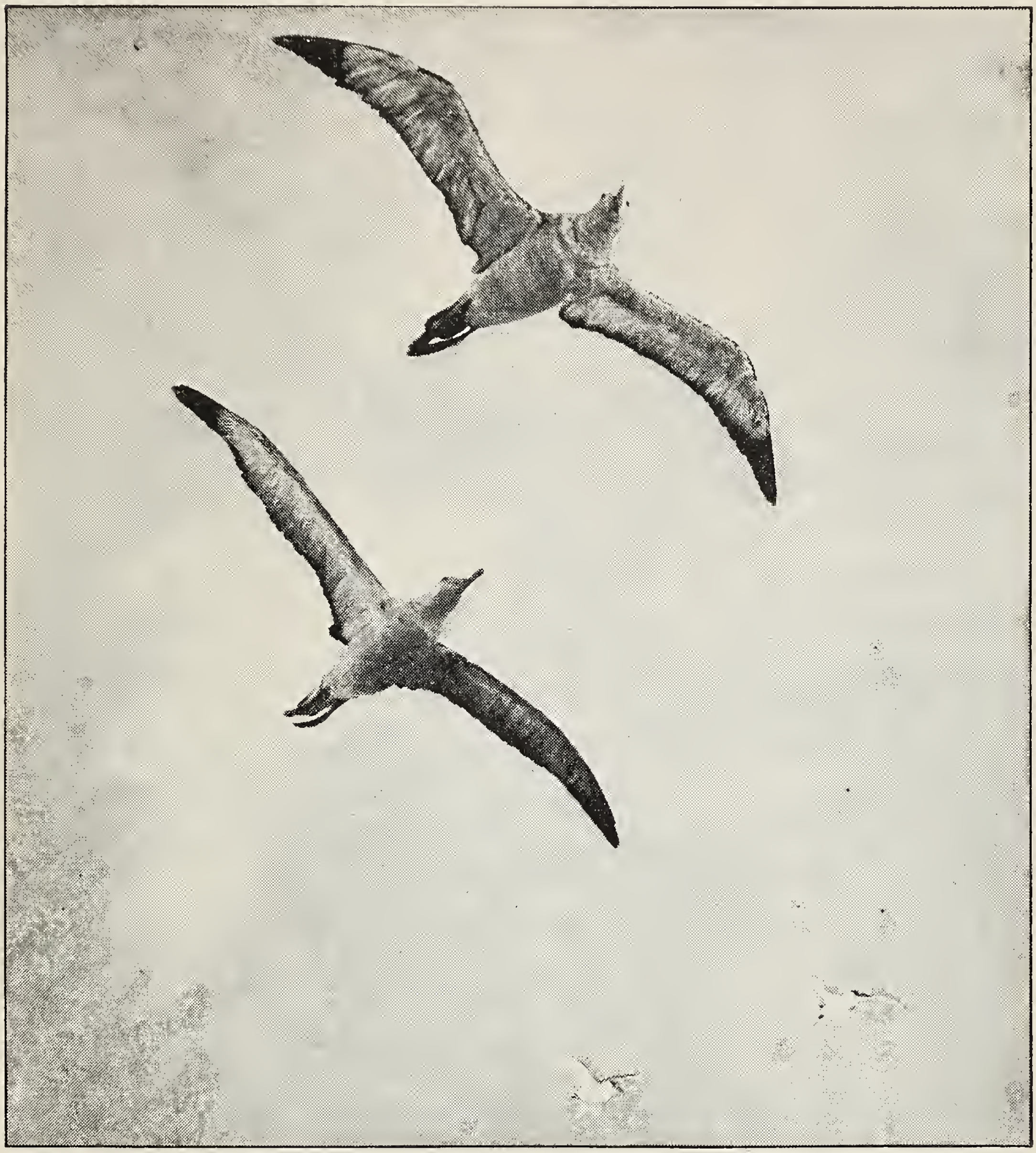

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Fig. 10. Albatrosses sailing

tips. One of the effects of this is to produce an air stream over the top of the wing which tends to prevent stalling.

Frigate birds. Sailing is definitely one of the most specialized and demanding types of flight. It calls for special aerodynamic form that is not found in all flying animals, though many may approach it. One of the best examples of aerodynamic form and agility in the air, as well as ability to fly long and far, is furnished by the man-of-war birds, or frigate birds, which are found over some of the warmer seas. Actually there are five known species, of which one, the great frigate bird, is found in areas of the South Atlantic, the South Pacific, and the Indian

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Fig. 11. Frigate birds

Oceans. This bird (see Figure 11) has long pointed wings, a relatively small body,[7] and a forked, mobile tail. Its feet are very poorly developed, so that it is not at home on the ground; but it is, in truth, a pirate of the air.

[7] The over-all length is sometimes given as about forty inches, but this includes sixteen inches of tail.

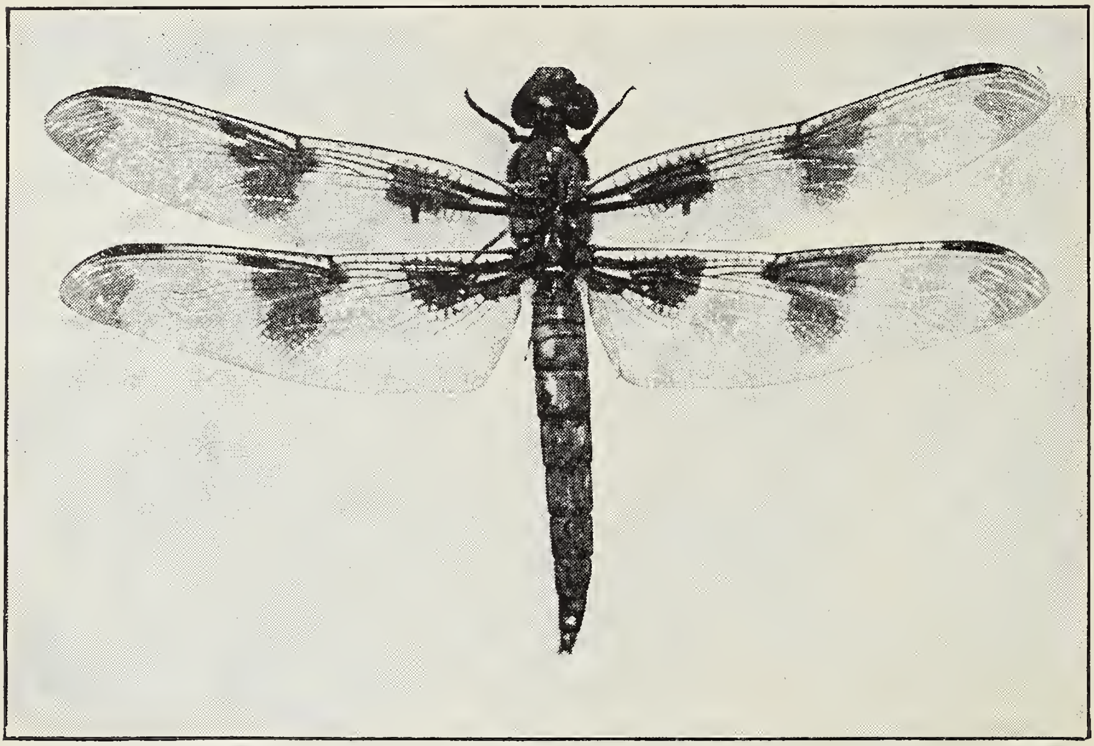
The man-of-war bird has sometimes been called the most completely aerial of all birds that follow the sea. When not roosting in a tree or sitting on a nest of eggs, most of its time is spent in flying or sailing about, and it remains aloft with apparent ease. Occasionally it dives down to the water and seizes a jellyfish or some other marine animal that has ventured too near the surface. A good deal of its food, however, consists of fish that it steals from other birds. A big, lumbering sea bird, for instance, may catch a fish and start back for land, hoping to enjoy a quiet meal. High above a man-of-war sees what has happened and dives down on the captor. The latter, disconcerted and sometimes badly shaken up by its crash-diving antagonist, drops the fish, and the agile air pirate continues on down to seize the prize before it falls into the sea. Then the man-of-war bird climbs back to higher altitude and proceeds to eat its stolen victim.

Such aerial ability depends upon aerodynamic form and good powers of co-ordination. One species of man-of-war bird has a wing spread of about seven feet, as compared with a body length of about two feet (less tail). The wings have a high aspect ratio (length compared with width), which means that they incline toward the long, narrow type. The tail can be altered as to form and position in terms of any aerial maneuver. Man-of-war birds do engage in flapping flight, as do all sailers when taking off, but much of their ability to stay in the air for long periods of time depends upon saving energy by soaring and gliding.

Albatrosses. Various kinds of albatrosses also are famous for their ability to sail. They do not possess the aerial agility of the frigate birds, but when it comes to sailing they probably are the champions. Albatrosses have wings of the long, narrow type, with an aspect ratio of 5:1 or more. In taking to the air, they first beat their wings and run along over the surface of the water for some distance into the wind. Having laboriously gotten up into the air, they tuck their feet back (like the retraction of a plane's landing gear) and are quite at home.

It has been suggested that albatrosses are able to sail hour after hour because they take advantage of unequal wind speeds at different heights and vertical pulsations of the air over waves. Certainly they are unable to perform so well when there is a dead calm, nor do they encounter the same air conditions that are to be found along a range of hills or the face of a cliff. Here again we must recall, however, that various factors enter into any attempt to explain sailing flight, and that all of the answers are not yet known by any means.

Flapping flight. Among animals, fast progress through the air is attained by those species that engage in what is here called flapping flight, that is, flight which depends primarily upon beating of the wings. Under this definition, the flight of most



Courtesy U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine

Fig. 12. A dragonfly

insects is of the flapping type, and we may profitably consider an example or two from this group of animals.

Figure 12 shows one of the many species of dragonflies that are often to be found along the borders of ponds and streams. These four-winged insects are by no means the fastest fliers, but their movements are controlled and remarkably well co-ordinated. One must remember that they are unable to change the shape of their wings while in flight, as can the birds. Dragonflies can, however, change wing positions and the rapidity of wing beats so as to control their movements in the air very well. For example, we may see one of them become perfectly still in the air; from this position it may move upward, downward, or to either side in a quick, darting manner.

You have probably noticed that the wings of some insects are quite large, but this does not necessarily mean that they are capable of strong or rapid flight. The fact is that many large-winged insects are poor or feeble fliers. The important point, rather, appears to be the number of wing beats per second. Some of the butterflies make about nine strokes per second, which result in a fluttering, rather uncertain flight. Dragonflies apparently stroke about twenty-eight times per second, with the result previously indicated.

The dragonflies, however, are greatly outclassed by some of the wasps, bees, and their allies (four-winged) and by certain of the true, two-winged flies. These rather small insects beat their wings so rapidly that the moving parts become invisible to the eye. The resulting flight is very rapid and often extremely well-controlled. Some of the bees and flies can stop dead in the air and then move quickly in any direction. Their aerial maneuvers are sometimes amazing, if not almost incredible.

It should be noted that certain of these fast, sturdy fliers are of the two-winged type, and that others possess four wings. Their wings are relatively strong and obviously powered by muscles capable of great exertion. Their bodies incline to be short and compact, although somewhat streamlined. The type of flight they exhibit calls for rapid use of energy, and it will not be a surprise to you to find that their adaptations are quite different from those of the soaring and sailing birds.

Wing motions of birds. The wings of birds, like those of insects, vary as to size and form. We have seen that those of albatrosses are long, slender, and pointed. Red-tailed hawks, broad-winged hawks, vultures, or eagles, on the other hand, have rather broad, rounded wings. Grouse and their allies have short, rounded wings that they beat rapidly to produce a bullet-like flight. Swallows and falcons have elongated, pointed wings, which are broad at their bases and are adapted to both speed and control.

Bird wings also have what is known as *camber,* an upward arching that produces a fore and aft curvature. This camber varies among different species; in fact, like other characteristics of the bird wing, it may be altered in the course of flight to meet varying demands. The bird wing is, then, a mobile structure, and the position of its parts can often be changed at will.

The average person would probably say that a bird beats its wings up and down in the process of flight. In a sense this is true, but it does not give a clear picture of what really happens, and it leaves a great deal unsaid. Actually the typical down beat is both *forward and downward,* and the camber of the wing is such that the bird is pushed forward [8] and at the same time supported or forced upward. In the up stroke, which is really *backward and upward,* some of the feathers bend downward and some separate so that air resistance becomes less; the bird is thus given an additional push forward. The forward motion therefore comes from both up and down strokes of the wings; [9]

Fig. 13. Wing motion in flapping flight

this is possible because their shape and curvature can be changed so readily.

Practically all birds move the two wings up and down at the same time, but some of the swifts (chimney swifts) are an exception. They often use their wings alternately, especially when they are making turns in the air. This may be of advantage to them, because they certainly maneuver with great skill and manage to catch insects while flying at speeds of over fifty miles an hour.

It is well known of course that birds use their wings as well as their tails in steering a course through the air.

Flight combinations. Anyone who has watched crows fly knows that they flap their wings in a steady and almost monotonous fashion. Now and then, however, a crow will glide or even soar. So it is with many common types of birds; their flight

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[8] On the down stroke the front margin of the wing is lower than the back margin of the wing.

[9] The same point has also been claimed in the case of some insects, although their wings are not flexible like those of birds.

is usually of the flapping type, but it also includes other kinds of behavior. Of similar interest are the ways in which various birds take off, or begin flight. A startled mallard duck will leap upward out of the water with amazing speed. A coot, on the other hand, must run along the surface, kicking the water with its feet for some distance before it finally takes to the air.

There can be no doubt that energy is used at a rapid rate while a bird is getting under way. During the period while the bird is gaining speed at the beginning of flight, it may use about eight times as much energy as it will when normal flight speed has been attained. The problem is basically like that of getting an airplane up off the ground or the water and gaining desired altitude and normal speed of flight.

Flight speed. The flight speeds of most common birds appear to average less than fifty miles per hour. Tame pigeons, for example, are credited with thirty to thirty-six miles per hour,[10] ducks with forty-four to fifty-nine miles per hour, and falcons with forty to forty-eight miles per hour. This does not mean that greater speeds are not possible; as a matter of fact, a duck has been reported as going ninety miles per hour for a short distance. The fast fliers among birds, however, clearly are the swifts, for two types have been timed over a mile course at rates of from 171 to 200 miles per hour. Even greater flight speeds have been claimed for certain birds at high altitudes, but the fact of the matter has not been well established. The explanation given is that a bird, like a stratosphere airplane, encounters less air resistance at the higher levels and is therefore capable of moving faster.

The number of wing beats made per second has something to do with flight speed, but it is not the only factor involved. The load, or weight of the body to be lifted, for instance, must also be considered. Another important factor is the size and shape of the wing surfaces. Fast moving species, for example, usually have wings with little camber. Thus we should not be surprised to find that sparrows make about thirteen wing strokes per second, whereas the much faster swifts make only ten. Really rapid wing motions are made by hummingbirds; these may be about two hundred strokes per minute. The results, however,

[10] A championship homing pigeon, however, has been known to maintain fifty-five miles per hour for four hours.

do not consist so much of forward speed as they do an ability to poise in the air and to move upward, downward, laterally, or backward, after the manner of a dragonfly.

Migration

Previous mention has been made of the fact that some animals have secured widespread distribution because they are able to move through the air. Among travels of this sort are what we call *migrations,* although we should not think of them as the performances of flying animals alone. They amount to being extended movements across the face of the earth, often associated with trips to and from the places where the young are produced.[11] Some of our mammals migrate, and they must walk to do so. Certain species of salmon perform remarkable journeys from the sea to their spawning grounds at the headwaters of inland streams.

Flying organisms, such as some birds, bats, and insects, do migrate, however; and usually their migration is more or less typical of the members of a given species. It may be found, for instance, that species A migrates annually to a given area and back again. Species B may not migrate at all, or most of its members may follow quite different routes. Some phenomena described as insect migrations seem to be caused by abnormal increase of numbers coupled with scarcity of food. Under such circumstances in past years vast swarms of Rocky Mountain locusts have been known to develop a migratory habit and to travel across country, destroying vegetation as they went. With this in mind, it is interesting to note that swarms of grasshoppers have been sighted 1200 miles at sea.

Extent of migrations. A number of our common birds move south in the fall for only relatively short distances; a good many of them do not get south of the United States borders. Others, however, perform long journeys over land and sea. In the latter class is the arctic tern,[12] which may cover a north and south distance of about 22,000 miles (round trip) in the course of a year.

[11] Some authorities would limit use of the term *migration* to travels to and from the breeding grounds. Thus they make a distinction between travels for such a purpose and the more or less casual wanderings in search of food or for other reasons.

[12] Terns are semiaquatic birds, related to gulls, which are often found along seacoasts or in the vicinity of large lakes.

Adult birds may nest along the Labrador coast of North America and then even cross over to Europe and go south over or along the coast of Africa to reach their goal in the Antarctic region. Actually their total mileage must be far greater than the shortest distance between summer and winter homes.

The thought that migrating birds cross oceans may come as a surprise to some readers, but they do in a number of cases. The Pacific golden plover,[13] for example, travels between Hawaii and Alaska, along a route that calls for a 2000-mile flight over water.

Another famous migrant is the golden plover, which nests along the southern border of the Arctic Ocean and winters far down in South America. In the autumn adult [14] golden plovers work their way down to the Labrador region, where they feed for a time upon ripe berries and become quite fat. Then they strike out southward over the Atlantic Ocean on a course that takes them far east of land. They must cover a distance of over 2000 miles before they reach the shores of South America, which they will do unless driven out of their way by storms.[15] When the birds complete this long flight, they are ounces lighter in weight, which is of course to be expected. Nevertheless, they continue on down to Argentina. Their northward route in the spring goes over the Central American region and up the Mississippi Valley.

Many different kinds of birds regularly cross the Gulf of Mexico.

Height and speed of migration. Some birds really fly high, and many of them migrate at altitudes of between 2000 and 5000 feet. This is not the upper limit, however, because cranes have been observed at a height of 15,000 feet. Most species do their traveling at night, but some seem to prefer the daytime, and others travel both times. Average distances covered per day are not so great (except in over-water flights) as might be expected. A robin, for example, may work its way northward from Louisiana to Minnesota at a rate of about thirteen miles per

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[13] Plovers are shore birds, related to such types as snipe and sandpipers.

[14] Strangely enough, the young birds follow a different route. They work southward over land and do not accompany the adults on the Atlantic crossing.

[15] In the fall storms have been known to blow in flights of golden plovers to our eastern coast.

day (in the spring). Then it speeds up its travels and may cover seventy miles a day before it reaches its destination in northern Canada. Such average distances are kept at rather low figures because of the fact that the birds often stop to rest and to take advantage of good feeding opportunities. In a similar fashion early autumn movements southward may be quite leisurely.

How do birds find their way? One of the most challenging questions about migration concerns the problem of how birds find their way. That they do so very well indeed is indicated by the flight of homing pigeons and by the fact that many birds return to the same nesting sites year after year even though they may have wintered thousands of miles away. It can of course be argued that birds have excellent vision, as suggested both by their behavior and by the structure of their eyes, and that they combine this advantage with good memory to follow natural landmarks, such as coast lines, valleys, and mountain ranges. This, however, would not explain some flights across oceans or the travels of young birds over areas that must be unknown to them.[16]

Other data also indicate that something more than recollection or good memory is at work. Some students of the subject removed terns from their nests and carried them 850 miles north along the Atlantic coast. The birds could not have seen where they were going, and there were reasons for believing that they probably had not been in the area to which they were taken. Nonetheless, when they were set free, they soon returned to their nests.

It appears therefore that we cannot fully answer the question, "How do birds find their way?" No doubt memory has something to do with the matter, but it does not seem to explain all cases. It has been suggested that birds may have a special sense of direction, which guides them over unknown tracts of land and sea. The existence of such a sense, however, has not been proved.

Why do birds migrate? We have seen that some local wanderings (not properly called migrations) are merely for purposes of finding food, and that migrating grasshoppers (see page 32)

[16] As in the fall migration of young golden plovers (see page 33), which are not accompanied by older birds.

represent a special case,[17] in which more than one cause seems to be responsible for the migratory urge. The journeys made by various species of fish are clearly for the purpose of laying their eggs. Similarly the northward movement of many birds in the spring of the year is associated with the fact that the nesting season is approaching.

It has proved difficult, however, to find a simple, clear-cut cause of bird migration that will explain all cases. Various explanations have been suggested. Some people have said that birds developed the migratory habit when ice sheets of the last great ice age drove them southward from their original homes. Various migratory birds, however, have evidently had tropical origin, and it is also true that the travels of certain species are more east and west than they are north and south.

Another popular idea is that migrations are for the purpose of finding better places to feed. In this case again the explanation does not satisfy, because many cases are observed in which birds deliberately leave good feeding grounds. In fact, if food were the only incentive, we would expect many insect eaters to remain in the tropics the year round.

It is often stated that birds are "driven" south by the cold as winter approaches. Some species, however, winter in the north, as we all know from our own observations. Moreover, many birds show little or no ability to anticipate changes in weather. Again and again migrating types have been known to come north in the face of late spring storms and blizzards. Still another theory is that the northland provides "safer" nesting sites; but, on the other hand, many tropical birds flourish without leaving the warm countries.

None of the foregoing theories, then, seems to fit all known cases, but it is still possible that there is truth in some or all of them. Recent experiments have shown that the urge to migrate seems to be associated with day length.[18] In the autumn, as the days become shorter, a bird's gonads (either male or female sex

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[17] It is not unique, however, for the European lemming (a small rodent) engages in a mass migration when it becomes numerous in its home area.

[18] It may be interesting to note that the time when some plants flower is determined by day length and can be controlled by using artificial lighting.

organs) decrease in size, and the migration southward begins. In the spring, as the days become longer, the gonads increase in size, and the birds begin their northward travels.

Summary

In conclusion, we may again note that the true fliers are found among the insects, bats, and birds. We have seen that their adaptations for flying vary greatly, as do the types of flight that they exhibit. Some species fly and glide feebly, others sail with almost effortless ease, and some move with bulletlike speed on fast-beating wings.

We can now see more clearly some of the advantages that flight brings to an animal. We have noted that migrating birds may even cross oceans, as well as mountain ranges and deserts. We can understand why such a group has become widely represented all over the world.

3

ALTITUDE EFFECTS

UP TO this point we have considered the organisms that fly and their adaptations for flying. Beginning with this chapter and continuing throughout the rest of the book, the discussion will have to do largely with the conditions met in flying that are harmful to the human body in one way or another or that may involve the spread of disease. Effort will be made not only to describe the harmful conditions met in flying, but also to explain how the dangers can be avoided.

In this chapter and the following one, consideration will be given to two topics that are related and that are of great importance to the one who flies. These are pressure and temperature and their effects upon the human body. The subject of pressure is very important, for it is necessary to an understanding of much that follows. It is therefore highly desirable that this material be well studied and thoroughly grasped before going farther. It is vital that the law relating to partial pressures of gases be well understood, and that the means by which the body obtains its oxygen and gives off carbon dioxide be recognized as a movement of these gases from a place of high pressure to a place of low pressure.

The Atmosphere and Respiration

The atmosphere. The ocean of air that engulfs the earth, as you perhaps know, is called the atmosphere. When we rise up in it to great heights, differences between being in the air and being on the ground become evident. Some study of the atmosphere and normal respiration, or breathing, is necessary if we are to understand the biological effects produced by flight.

The atmosphere extends approximately 300 miles above the earth and contains the same gases up to at least 72,000 feet.

The chemical make-up of dry air at the surface of the earth is about 78 per cent nitrogen, 21 per cent oxygen, .03 per cent carbon dioxide, and nearly 1 per cent rare gases, such as argon and helium.

Temperature. The temperature of the air near the surface of the earth varies greatly at different places on the globe. There are also wide differences of temperature in any one place

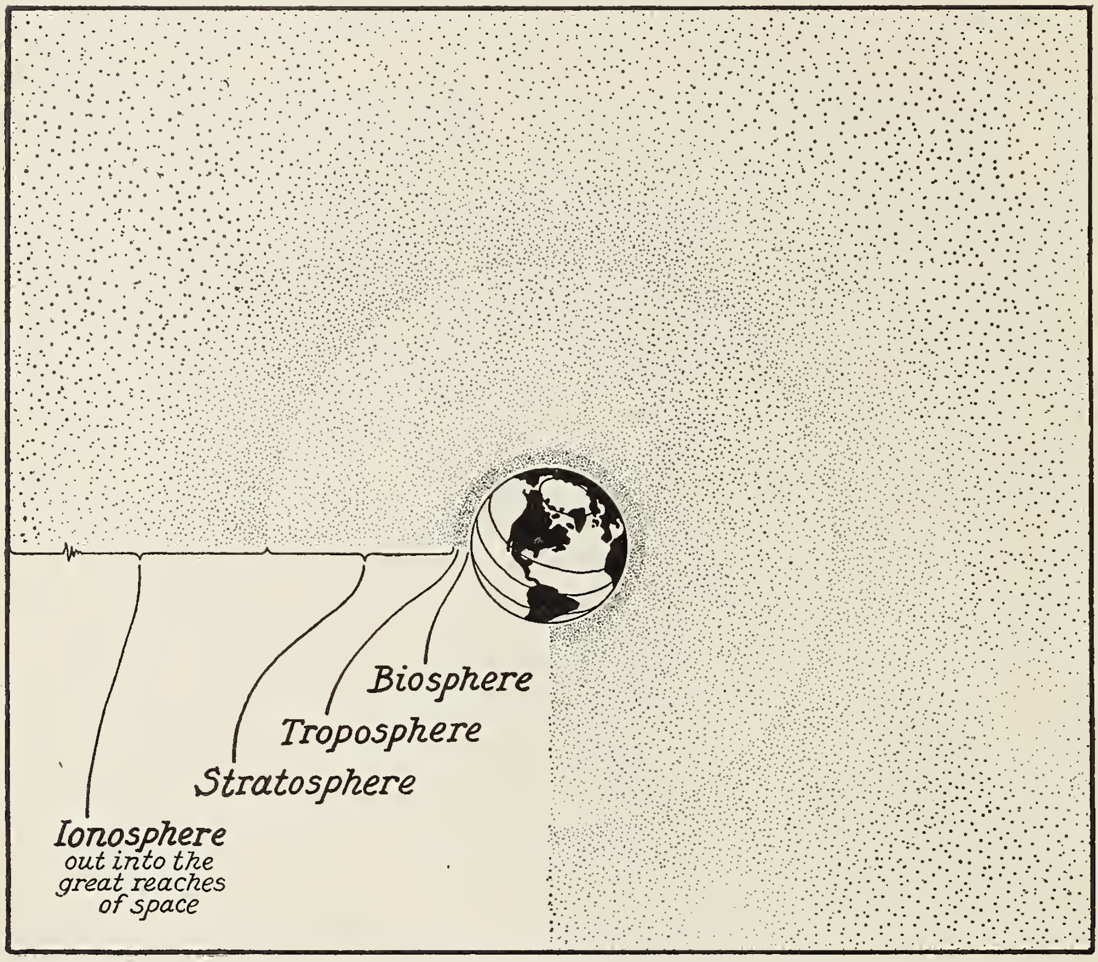

Fig. 14. The layers of the earth's atmosphere

during the changing seasons of the year. On the average, however, the air tends to become colder at the rate of about 1° F. for each 280 feet of increase in altitude until the stratosphere is reached.

The stratosphere is a region of the atmosphere that begins at a height of about six or seven miles [1] in the temperate zones and extends upward. At its base the average temperature is about —67° F. Strange as it may seem, the base of the stratosphere is

[1] The height of the stratosphere over the tropics is ten miles, over the temperate zones six or seven, and over the poles only four or five.

coldest over the equator. Thus, contrary to what one would expect, the coldest place near the surface of the earth (about —115° F.) is perhaps twelve miles above the tropics.

Pressure. Pressure, like temperature, also decreases with altitude. While we are not conscious of the fact, it is well established that air has weight. As a result, each layer of the atmosphere is weighed down by the layers above, causing the air at the lower levels to be more dense because it is under the pressure of a greater mass above. The atmospheric pressure at sea level is 760 millimeters of mercury. This means that it is equal to the pressure that will support a column of mercury 760 millimeters (29.92 inches) in height. This amounts to 14.7 pounds of pressure per square inch.[2]

The normal pressure of 14.7 pounds per square inch is sometimes called one atmosphere. This same pressure exists inside as well as outside all organisms that live under sea-level conditions. The higher we climb in the atmosphere, the thinner becomes the blanket of air pressing down upon us and the lower becomes the atmospheric pressure. This decrease of pressure is not constant per unit of distance; it is most rapid near the earth's surface and is less marked at the higher altitudes, as shown in Table I.

TABLE I

RELATION OF ALTITUDE TO PRESSURE

Altitude in feet	0	1000	10,000	20,000	30,000	40,000	50,000	60,000	66,000
Atmospheric pressure in millimeters	760	733	522.6	349.2	225.6	140.7	87.3	54.1	40.99

The biological results of such pressure differences will be more easily understood in the light of Dalton's law. This law states that in a mixture of gases each gas exerts a partial pressure equal to that which it would produce if it alone occupied the whole space occupied by the mixture. Let us see how this applies to the human problem of obtaining oxygen. The total

[2] One pound per square inch equals 2.03 inches, or 50.8 millimeters, of mercury.

atmospheric pressure at an elevation of 1000 feet is 733 millimeters; and, since the air contains 21 per cent oxygen, the partial pressure of oxygen is 21 per cent of 733, or over 153 millimeters. Likewise, it is also true that the partial pressure of nitrogen in the air amounts to 78 per cent; and 78 per cent of 733 is over 571 millimeters, which is the pressure of nitrogen at this height.

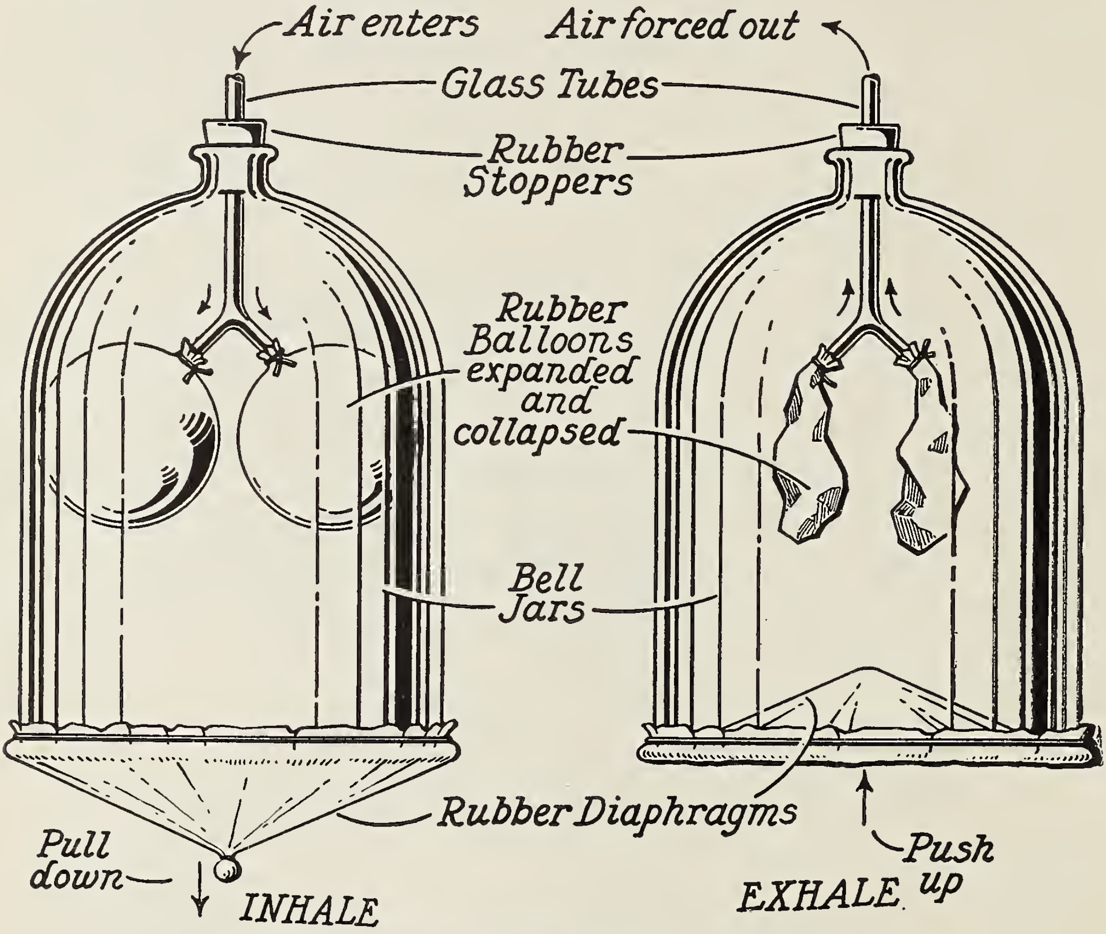

Fig. 15. An apparatus that shows how breathing occurs

How breathing takes place. Normal respiration (as at sea level) takes place because the partial pressure of the oxygen in the air is higher than it is in the blood. Therefore the atmospheric oxygen diffuses from the lungs into the blood stream. However, when the partial pressure of oxygen falls, as at high altitudes, less oxygen passes into the blood, and the tissues of the body soon suffer from oxygen lack. Before discussing the latter condition, however, let us consider the normal process of breathing.

There are two chief reasons why we need to breathe. The first reason is to obtain oxygen from the air to be used by the body tissues in oxidation and the release of energy. The second is to rid the body of carbon dioxide, which is a waste product of oxidation.

The mechanics of breathing are as follows: Taking air into the lungs is accomplished by a combination of two movements—(1) the muscles of the diaphragm contract, causing it to move downward; (2) certain muscles attached to the ribs contract, causing the ribs to be pulled upward. Both of these movements enlarge the chest cavity and thus reduce the pressure between the lungs and the walls of the lung cavity. The lungs expand until they nearly fill the space around them in the lung cavity, with the result that the pressure of air within them falls below that of the atmosphere by 1 to 2 millimeters. The greater atmospheric pressure outside the body therefore forces air into the lungs until the air pressure inside and outside these organs is equal.

The air is forced out of the lungs in this way: The diaphragm pushes upward. The ribs sink downward. The chest cavity becomes smaller in size; therefore the lungs are compressed. This results in air being forced out of the lungs until the air pressure is the same on the inside of them as it is outside.

An adult usually breathes on the average of about sixteen to eighteen times per minute. The rate is more rapid in the case of children and may be more than forty times a minute for young babies. Breathing is slower but deeper during sleep.

Oxygen is forced through the lungs into the blood under a pressure of about 100 millimeters at sea level. The blood then receives about 95 per cent of the oxygen it is able to carry, or about a full load. As the blood is carried through the smallest blood vessels to the tissues, its oxygen pressure is still nearly what it was when it left the lungs, while the oxygen pressure in the surrounding tissues amounts to only a few millimeters of mercury. As a result of this difference, oxygen from the blood flows through the walls of the blood vessels and out into the body tissues.

On the other hand, the partial pressure of carbon dioxide is higher in the tissues than it is in the blood, and therefore this gas flows from the tissues in which it is produced into the blood stream. Thus it will be seen that the blood flowing to the lungs is low in oxygen and high in carbon dioxide. As the blood passes through the lungs, carbon dioxide is thrown off and oxygen picked up. The carbon dioxide is expelled from the lungs when the breath is exhaled.

Control of breathing. The flier should know the mechanism by which breathing is controlled. Many people incorrectly believe that breathing is regulated mainly by the oxygen needs of the body. On the contrary, the chief factor concerned is the amount of carbon dioxide in the blood. When one engages in strenuous exercise, a greater amount of carbon dioxide is formed in the body. When the amount of carbon dioxide in the blood increases beyond the normal, a regulating center in the medulla of the brain is stimulated, with the result that the breathing rate is speeded up. This is the reason why it is hard to "hold the breath" very long. The amount of carbon dioxide in the blood soon becomes relatively larger, and the result is a growing stimulation of the breathing center that is difficult to resist.

On the other hand, it has been shown that, if a person's supply of oxygen is cut off and if he breathes an inert gas such as helium so that he is able to get rid of carbon dioxide in a normal way, there is only a slight increase in the breathing rate, even though the experiment be carried to the point of near-death. Such results indicate that oxygen lack plays only a minor role in causing a person to breathe. Anyone can prove to himself that carbon dioxide is the chief factor involved by practicing forced breathing (breathing deeply and rapidly) for a minute or so. When this is done he will have no desire to breathe for about a half minute. After a period of forced breathing one can hold his breath much longer than under normal conditions. The reason for this is quite obvious; the overventilating of the lungs removes the carbon dioxide of the body to such an extent that some time is required for the carbon dioxide content to build up again and produce an urge to breathe.

If the forced-breathing experiment is tried, it will be found that rapid forced breathing soon causes a feeling of faintness and dizziness, which are the symptoms that accompany the fall of carbon dioxide below its normal level.[3] When these symptoms are experienced, the forced breathing should be stopped

[3] The practice of carrying on forced respiration is not recommended; it is said to induce a state of mental confusion in some cases.

at once. It is interesting to note in this connection that reduction of carbon dioxide in the body below the normal amount is one of the dangers of high altitude flight. Incidentally some of the magician's unusual feats are possible because he understands the relation of oxygen and carbon dioxide to the breathing process. Some magicians have inhaled oxygen during a period of forced breathing, after which they were able to hold their breath for as much as fifteen minutes. One noted performer used this technique so well that he could stay under water for a quarter of an hour.

In summary, we may say that the breathing rate is speeded up by an increase of carbon dioxide in the blood, and that it slows down when the amount of carbon dioxide is lessened. An increase of oxygen in the blood has no effect on breathing, and a decrease causes only a minor increase in the breathing rate.

Altitude Sickness

Anoxia. Having considered some of the facts about breathing, let us see how the process is affected when men go up into the air. Early experiments on the effects of high altitude go back about 160 years, when attempts were made to conquer the air by balloon. The first passengers to go aloft were a chicken, a duck, and a sheep. All of them returned to earth unharmed. Nearly one hundred years later one of the most famous of early balloon ascensions was made by three scientists, Sivel, Crocé-Spinelli, and Tissandier. The balloon rose to 28,820 feet. Tissandier, who was the last of the three to be overcome, became unconscious at about 26,000 feet. His two companions died; but Tissandier, although in a serious condition, lived to tell the dramatic story of this tragic flight.

Tissandier suffered from what is now known as *altitude sickness,* which is the term used to describe a high altitude illness that results from lack of oxygen. This basic condition is variously called oxygen want, oxygen lack, oxygen deficiency, and *anoxia.* Anoxia is a favored medical term, which may be used to include all conditions of oxygen want in the body.

An important aid to research concerned with the effects of high altitude upon man is the altitude chamber, an airtight chamber with strong walls. By lowering air pressure it is possible to create in it the conditions at various altitudes. The altitude chamber is used to study effects of oxygen lack and also other disorders that may be developed in the upper air.

Cause of anoxia. Inasmuch as the oxygen percentage remains the same at all heights, it is apparent that altitude sickness cannot be due to a decreased percentage of oxygen in the air. But the partial pressure of oxygen falls as altitude is increased.

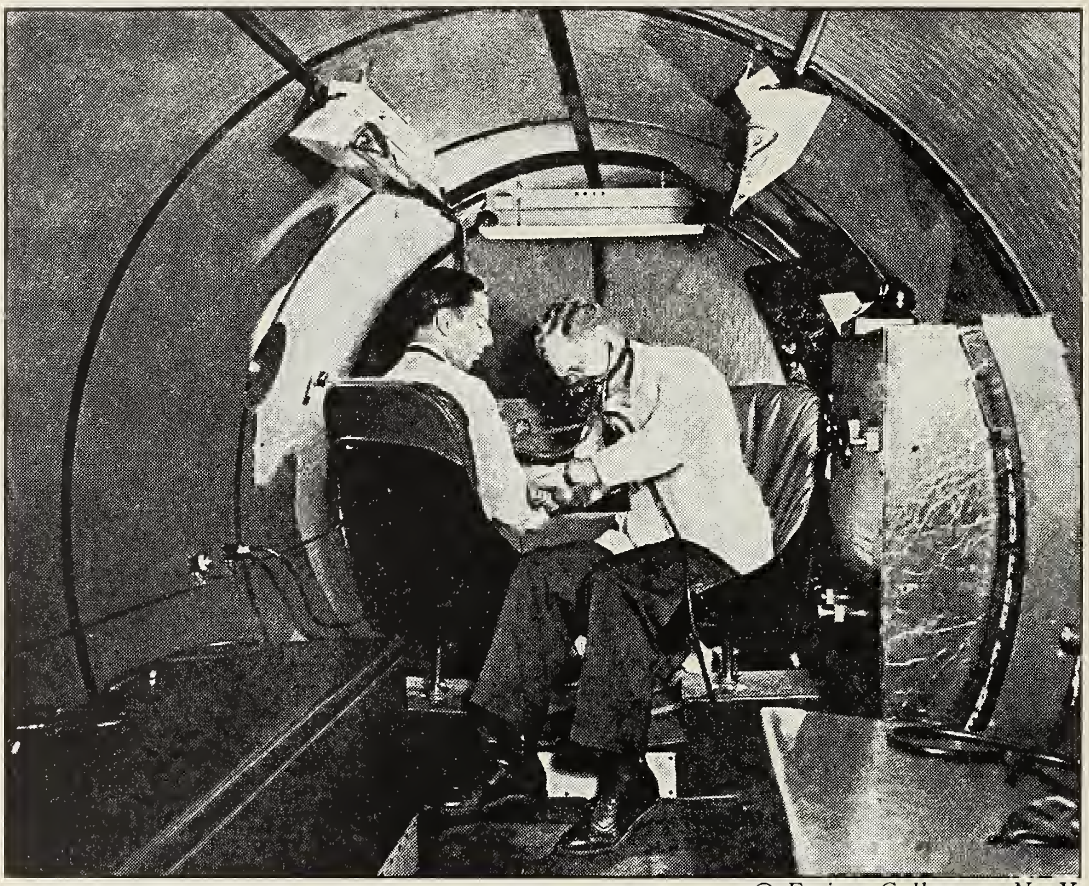

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Fig. 16. Interior of an altitude chamber

This is the real cause of oxygen lack, because the oxygen supply of the body depends upon the partial pressure of oxygen that is taken into the lungs. Table II shows how the partial pressure of oxygen in the lungs falls with increase in altitude.

TABLE II

RELATION OF ALTITUDE TO PARTIAL PRESSURE OF OXYGEN IN THE LUNGS

Altitude in feet	0	10,000	20,000	25,000
Partial pressure, in millimeters, of oxygen in the lungs	103	58	37	34

Man has long been an earth-dwelling animal; nevertheless, he fortunately shows some adaptations useful in flight. For example, as one climbs to a high altitude the lack of oxygen stimulates the breathing rate. But the increased breathing causes an abnormal amount of carbon dioxide to be washed out of the blood. Then the control center of the brain acts to slow down the breathing rate again. Thus it can be seen that the two factors regulating breathing, oxygen and carbon dioxide, oppose each other at high altitudes. The normal result is a sort of compromise. If oxygen want alone controlled the breathing, then the respiratory center would be so stimulated at 11,000 feet that one would be gasping for breath. On the other hand, if carbon dioxide alone were responsible, no amount of oxygen lack, even to the point of death, would speed up the rate of breathing. At high altitudes, where both of these factors are at work, the net effect is a gradual increase in breathing rate.

If the amount of oxygen in the blood passing through the lungs were directly proportional to the partial pressure of oxygen in the lungs, then one would probably collapse from oxygen lack at an altitude of 12,000 feet or less. The fact is, however, that this does not happen, as some people live at such heights above sea level, especially in mountainous countries. Actually the amount of oxygen that can be taken up by the blood depends on, but is *not directly proportional to,* the pressure of oxygen in the lungs. In other words, red blood cells retain a good deal of oxygen for a long time, even though partial oxygen pressures in the lungs are being reduced. For example, it will be remembered that at sea level the partial pressure of oxygen in the lungs is about 100 millimeters and the blood is about 95 per cent saturated with oxygen, but when partial pressure of oxygen in the lungs sinks to only 40 millimeters the blood is still about 70 per cent saturated with oxygen.

Symptoms of altitude sickness. Altitude sickness is especially dangerous because no condition known can produce less pain and yet cause such great bodily injury or even death. In fact, some persons actually feel "better" when having a severe attack.

The first evidence of oxygen lack usually appears at about 5000 feet. At this elevation the rate of breathing is increased slightly, but this fact may not be observed by the person concerned. There may also be a rise in the pulse rate and in blood pressure. Photographic records of the heart's action at 5000 feet show that certain changes take place which have been interpreted as signs of heart damage. These studies have led one investigator to recommend that oxygen be used at 5000 feet rather than at 10,000 feet, as is usually done.

Above 15,000 feet there are likely to be signs of breakdown in both physical and mental functions. Sight, hearing, and muscular co-ordination begin to fail.

It cannot be emphasized too strongly that people vary greatly as to the effect of oxygen lack upon them. For example, some people react to high altitude by becoming dull and listless, while others feel abnormally well and become quite active. In neither case, however, is the abnormal feeling recognized as anything unusual by the victim.

It is interesting to note the parallel between the effects of oxygen lack and alcoholic intoxication. Both have symptoms that are alike and that probably arise from similar causes. In altitude sickness the body tissues suffer from a lack of oxygen. In drunkenness alcohol gets into the blood and the tissues become bathed with this poison, which makes it impossible for the cells to utilize the available oxygen. Altitude sickness at one stage of its development produces a happy emotion of "altitudinal intoxication," in which the aviator has no thought of danger; on the contrary, he enjoys a feeling of such bliss that he may forget the purpose of his flight. He lacks a sense of responsibility and critical judgment, sometimes failing to appreciate the need of using his oxygen. These effects, like similar symptoms of drunkenness, are thought to result from failure of function in the highest center of the brain, namely, the cerebrum.

Effects of higher altitudes. As one ascends to even higher altitudes more severe symptoms of altitude sickness appear. At about 18,000 feet eyesight is impaired and the ability to feel pain is usually so lessened that one may suffer a serious injury, such as that from a sharp instrument driven through the hand, without much discomfort. Hearing may be so poor that the motor does not appear to be running. One Alpine expedition reported that hearing at a high altitude was so imperfect that the thunder of avalanches was hardly audible. In addition, some people cannot taste onions or mint tablets at an altitude of 19,000 feet.

Consciousness is usually lost at an altitude between 18,000 and 25,000 feet. Mental behavior at such heights is varied; sometimes outbursts of anger occur, but more often the individual is gay and silly, making faces and laughing for no reason. When unconsciousness occurs, death is near. Death from anoxia, which is probably always due to failure of the respiratory center to function, takes place in about ten to fifteen minutes at 25,000 feet.

Modifying factors. From what has been said regarding indi-

Fig. 17. Burning candles at different altitudes

vidual differences you can see that it is unsafe to make positive statements about the effects of altitude sickness. Not only will people behave in various ways, but also the same person will not always react in the same manner to the same altitude conditions.

Some of the factors that modify the nature of the reaction seem worthy of mention. It makes no difference, for example, whether a person travels in a balloon or an airplane, for the present-day speeds of forward movement have little if any biological effect. However, the rate at which one rises vertically in the air is of great importance. An ascent of 5000 feet per minute in a plane is one thing and a climbing expedition in the mountains is another, for in the latter case the body has an opportunity to adjust itself over a considerable period of time. In airplane flights it has been found that gaining altitude too rapidly does not allow the body time to make adjustments; on the other hand, a slow rate of altitude gain (200 feet per minute) may not be desirable because the flier is exposed to each altitude level for a longer time. The length of exposure to rarefied air is also important, for it is now known that some persons can react nearly normally for fifteen minutes at 17,000 feet, but that the same persons may be prostrate after three hours' time. Thus in general it may be said that altitude sickness is not only proportional to the altitude, but also to the length of exposure.

If the activity of the body is increased, there is a corresponding increase in need for oxygen. Walking requires three to ten times as much oxygen as sitting quietly requires. Mountaineering calls for a great deal of effort, whereas flying makes far less demand. Certain symptoms of altitude sickness that occur in flight at heights of about 15,000 to 18,000 feet may appear at much lower altitudes (10,000 to 12,000 feet) in the case of a mountain climber who is not used to this activity. He is commonly said to have *mountain sickness,* which is brought about by anoxia. On the other hand, studies of mountain expeditions made in the Himalayas, where it takes months of slow climbing to reach an altitude of 23,000 feet, show that even at this height the climbers suffered no great distress.

In the Andes there is a large group of Peruvians who live at an altitude of 10,000 to 16,000 feet. These native Andeans are able to carry on their normal work without suffering any ill effects, probably because they are the product of centuries of selection. People who are acclimatized to altitudes of more than 12,000 feet show many interesting adaptations. One of these is an increase in both size and number of red blood cells. At sea level the normal blood count is 4,500,000 to 5,000,000 red blood cells per cubic millimeter, but persons who remain at heights of 14,000 feet for two or three weeks develop a blood count of about 6,000,000 to 7,000,000. It has been shown that the reduced oxygen content of the air breathed leads to a deficiency of oxygen in the blood. This in turn stimulates the red bone marrow to produce more red blood cells, which compensate for the low partial oxygen pressure of the atmosphere.

Other adaptations to rarefied air are increase in the hemoglobin content of blood, an increase in the size and capacity of the chest, and an increase in the size of the heart. Also of great importance is the fact that certain changes in the chemical content of the blood[4] occur. These changes tend to get more rarefied air into the lungs and a normal amount of oxygen to the tissues. The temporary nature of airplane flights of course does not provide time for adjustments like the foregoing to take place.

Finally, the general physical condition of a person has a great effect on his tolerance of altitude. Any physical condition that results in lowered vitality, such as lack of sleep or a cold, reduces a flier's ability to withstand oxygen want. Since alcohol in the body interferes with use of oxygen by the tissues, it would be expected to reduce altitude tolerance.

We can summarize by saying that while the degree of altitude sickness depends mainly upon the height to which one ascends, modifying factors do exert a great effect. These factors include the rate of ascent, length of exposure, individual differences, activity, and general physical condition.

Chronic symptoms. Our discussion of altitude sickness has thus far been concerned with the results of a single flight. There is another type called *chronic altitude sickness,* which is produced by many flights at high altitudes covering a long period of time. It is now known from experiments that repeated exposures to rarefied air have an effect on the body that is cumulative, and that tolerance gradually becomes less and less. After a time the result is chronic fatigue, sleeplessness, and nervousness, which make the pilot unfit for flying. Some people have shown an increase in the number of red blood cells, which seems to be an attempt on the part of the body to compensate for oxygen want. However, there is no evidence that any marked adaptation to high altitude occurs in the case of fliers.

Dangers of high altitudes. As previously stated, death may result from oxygen lack. Ignorance of pilots as to the seriousness of oxygen want, combined with the deceptive nature of the symptoms, has resulted in much avoidable tragedy. Many pilots have mistakenly thought that their altitude tolerance represented the altitude at which they could safely fly. Actually the altitude at which it is safe to fly depends on the upper limit of height at which a person's health is not injured after a

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[4] A new balance (at a lower level) between the carbon dioxide content and certain alkaline compounds is established.

period of time. The tendency has been more and more to recognize the dangers of high altitudes, and commercial transports (without special oxygen equipment) are now flown at a considerably lower height than formerly. Generally 10,000 feet has been considered safe for long flights; however, as we have said, one investigator has recommended that oxygen be used at 5000 feet. This suggestion may represent extreme caution, but no possible harm could result from using oxygen at a relatively low level; and, if one is more than usually active or has a low tolerance for oxygen want, the practice could be very beneficial. Naturally individual differences should also be considered in deciding how high it is safe for one to fly.

The cells of the brain and spinal cord are sensitive to oxygen lack. It has been shown that certain brain cells are completely destroyed by an exposure of eight minutes to absence of oxygen. There is also some evidence that oxygen want may cause an accumulation of fluid in the brain. Under such conditions the adrenal glands first grow larger but on repeated exposure begin to degenerate. Because altitude sickness resembles Addison's disease, which is caused by faulty function of the adrenal glands, there is a possibility that some symptoms of altitude sickness are produced by adrenal failure. This interesting problem needs more study.

Prevention and treatment of altitude sickness. Obviously altitude sickness can be prevented by flying below those heights at which it develops. If high altitude flying is necessary, oxygen should be provided; either a pressure suit should be worn or a pressure cabin used. If oxygen cannot be had, the harmful effects of oxygen lack can be lessened by sitting almost perfectly still and by increasing the depth while decreasing the rate of breathing. Deep breathing gets more air into the lungs; but, if the rate at which it is obtained is not slow, carbon dioxide will be washed out of the blood and dizziness will result. It will also be remembered that, if there is too little carbon dioxide in the blood, the breathing control center will not be properly stimulated.

If breathing ceases at a high altitude, artificial respiration should be started at once. Standard practice may be followed, and pressure should be applied about fourteen times a minute. In the excitement caused by such an event, there is danger of giving artificial respiration at too rapid a rate; if this is done, the overventilation of the lungs reduces the carbon dioxide of the blood and the natural stimulation for breathing is lost. A patient, after regaining consciousness from altitude sickness, should be allowed to rest for a day or more.

Oxygen. Oxygen is a colorless, tasteless gas that is slightly heavier than air. It is one of the most vital human needs. In order to live, our bodies must be continuously supplied with energy. This is released by a slow oxidation in the tissues. Un-

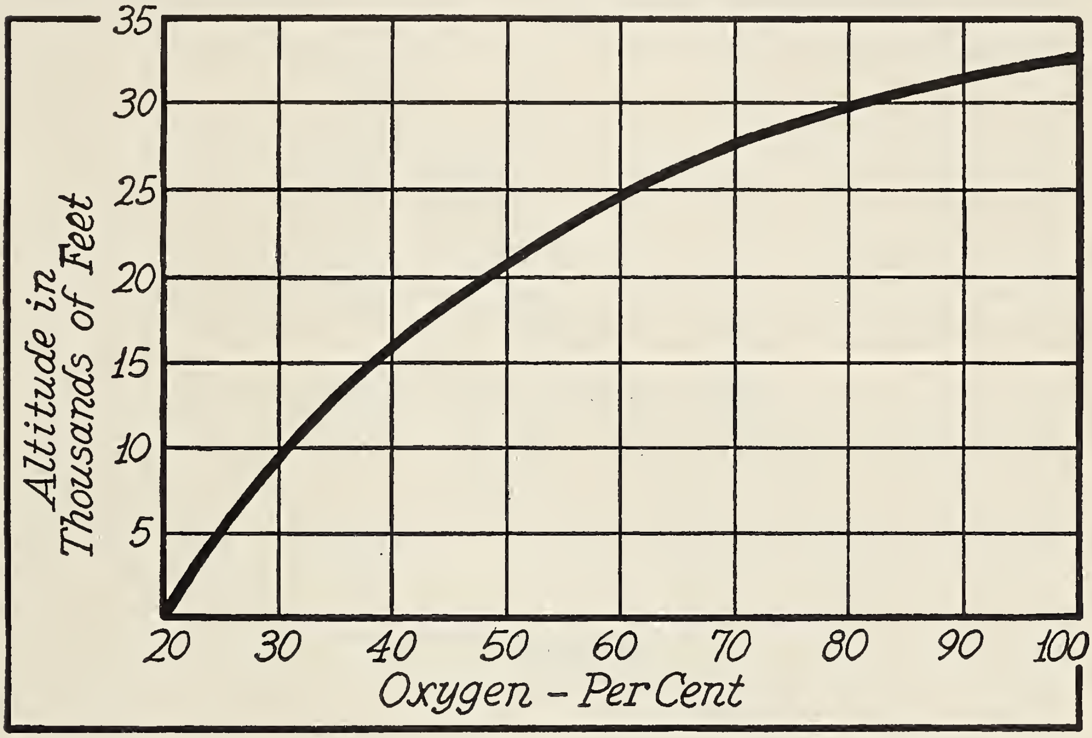

Fig. 18. The percentage of oxygen that must be in air to maintain a sea-level partial pressure at various heights

like some other substances essential to life, oxygen cannot be stored in the body in large amounts and must therefore be supplied as fast as it is used by the tissues. While one may go for weeks without food and for days without water, death comes in a few minutes from total lack of oxygen supply.

Altitude sickness, as we have seen, results from a reduced oxygen supply at high altitudes. That breathing pure oxygen will, within certain limits, prevent or cure altitude sickness is well known. This is because the partial pressure of the oxygen that is breathed in rarefied air can be increased by the use of pure oxygen. The amount of oxygen that must be added to air at high altitude to maintain a sea-level partial pressure of oxygen in the lungs is not directly proportional to the decrease of atmospheric pressure. This is explained by the fact that there is a constant pressure of water vapor in the lungs of 47 millimeters. Hence the amount of oxygen taken in must be increased more rapidly than the pressure is decreased.

Artificial adaptation to altitude. The flight of Tissandier and his two ill-fated companions was famous for a number of reasons. One of them was the fact that it was the first time oxygen was taken along. The oxygen was carried in small balloons, and because of their limited capacity it was decided not to

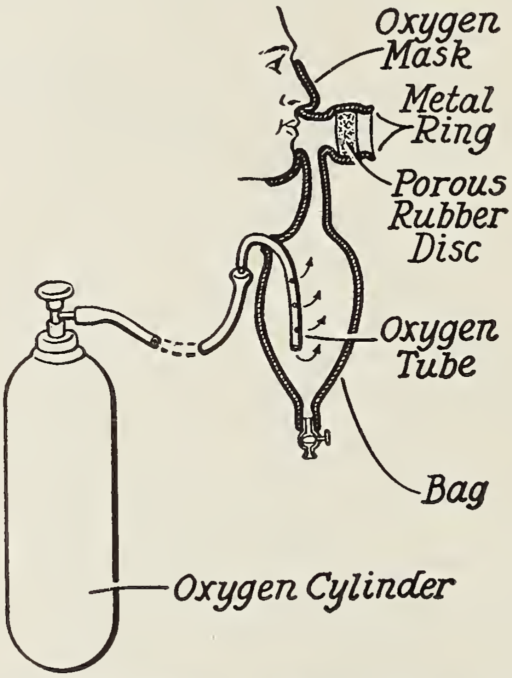

Fig. 19. Oxygen mask and cylinder

begin its use until a real need for it was felt. This need was not realized by the fliers until all were overcome, and it will be recalled that only Tissandier returned to earth alive. Unfortunately such accidents have happened again and again despite this early lesson.

In World War I the Germans used liquid oxygen to supplement the oxygen of high altitudes. It was contained in bottles with double walls; the space between the walls constituted a vacuum, such as that in thermos bottles. Loose-fitting caps were provided because of the constant evaporation of the liquid oxygen; if such bottles are sealed, dangerous pressures develop. One advantage of liquid over gaseous oxygen is that a given amount can be stored in less space. On the other hand, liquid oxygen cannot be kept for long periods of time under ordinary conditions of use because of the constant evaporation. Also, if liquid oxygen is spilled on the body, it is very injurious to the skin; and it is so cold that it is unpleasant, if not harmful, to breathe.

Today compressed gaseous oxygen is used almost throughout the world. The gas is stored in cylinders of light metal similar to the type shown in Figure 19. Pressure of the oxygen in these cylinders is about 2250 pounds per square inch. This makes it necessary to place a regulator somewhere in the line between oxygen tank and user, to reduce the oxygen pressure and to control its flow.

Early equipment for using oxygen consisted of a rubber tube or wooden pipestem held in the mouth, through which the oxygen from a tank flowed constantly. This arrangement was wasteful of oxygen, due to the fact that in breathing one inhales about one third of the time, so that approximately two thirds of the oxygen was lost.

An army modification of the B-L-B oxygen apparatus, so named because it was developed by Boothby, Lovelace, and Bulbulian, is one of the most recent types. This equipment is shown in Figure 19. Oxygen flows steadily into the rubber reservoir bag from the tube that is connected with the gas regulator. While the user is exhaling, the bag stores up the inflowing oxygen. As the wearer inhales, the oxygen collected is taken into the lungs until the bag is empty. When this occurs a slight suction or negative pressure [5] develops and air is drawn in through the porous sponge rubber disc in an amount sufficient to fill the lungs.

At the beginning of exhalation the air in the upper part of the respiratory organs (nose, trachea, and bronchi), which is relatively rich in oxygen, is returned to the rubber bag until it becomes slightly distended. As the bag enlarges a pressure develops in the mask, which causes the last part of the air exhaled to be forced out through the rubber disc, similar to

[5] Atmospheric pressure is taken as a point of reference. Pressures above atmospheric are called positive, those below atmospheric are called negative. It is obvious that these values are pressure differences with reference to atmospheric pressure. With reference to absolute zero all pressures are necessarily positive.

the way it was drawn in during the last stage of inhalation. This last air to pass out from the lungs is very poor in oxygen. Thus it will be seen that the bag contains the best air exhaled from the lungs, plus the oxygen that is flowing into it from the oxygen tank. During the next inhalation the mixture of air and oxygen from the bag is inhaled, and the whole breathing cycle is repeated.

This type of equipment prevents waste of oxygen and even conserves a large part of the unused oxygen in exhaled air. Moreover, the exhaled air in the bag helps to warm and humidify the cold incoming oxygen, and this is a distinct advantage. Oxygen taken from a plain tube often causes severe chapping of the user's lips because of its extreme dryness.

The metal ring (see Figure 19) is for the purpose of speaking. With this apparatus there is no difficulty in making the voice heard, either in ordinary conversation or over the radio.

Some military pilots formerly feared to employ oxygen, but as far as is known there have been no severe harmful effects from its use, but only those of a minor nature. Now the attitude of military fliers is completely reversed. At the present time all high altitude military planes in the United States Army are provided with oxygen equipment. It is believed that the general practice of using oxygen at altitudes of 10,000 to 15,000 feet has greatly reduced the number of aircraft accidents.

There are some special oxygen problems involved in military flight, one of which may be mentioned here. It is said that in World War II dogfights take place at 35,000 to 40,000 feet above the earth. At such heights planes may escape searching beacon lights, antiaircraft guns, and fighter planes. If the pilot has to "bail out," however, it probably takes about ten minutes to get down from 40,000 feet to a level where there is sufficient oxygen to support life. Therefore the substratosphere flier should be equipped with an emergency supply of oxygen for use in parachute jumps.

Special uses of oxygen are not limited to high altitude flying. It is also carried aboard submarines in case they must remain submerged for long periods of time, and it has proved valuable in rescue work, especially in case of mine disasters.

How high is it possible to fly with oxygen? Even when 100 per cent oxygen is breathed there is an altitude beyond which it is unsafe to go. Calculations as to the theoretical limit of ascent and the actual heights to which man has flown while breathing oxygen do not agree very well. Likewise it will be found that there is considerable disagreement among the experts as to how high one can safely go.

Undoubtedly some of this disagreement is due to the fact that people vary greatly in their tolerance of oxygen lack. While one is breathing pure oxygen the blood theoretically should contain as much oxygen at 33,000 feet as at sea level. From this point on, however, the partial pressure of the oxygen in the lungs and in the blood rapidly decreases, until at a height of about 40,000 feet the probable limit of altitude tolerance is reached. At about 51,000 feet the oxygen partial pressure in the lungs and the oxygen saturation of the blood reach zero. The explanation for this is that at such a height there is not much oxygen pressure in the lungs to cause the oxygen to flow into the blood stream; in other words, the oxygen pressure is insufficient to drive it into the blood (if we assume that a pressure cabin is not used).

The absolute limit for high flying is not known, but Commendatore Donati of Italy on September 28, 1934, reached an altitude of 47,358 feet in an open cockpit airplane. Theoretically Donati would have had only 12 millimeters of oxygen pressure in his lungs at this altitude. The atmospheric pressure would be 99 millimeters minus the pressure of 47 millimeters for water vapor and about 40 millimeters for carbon dioxide and nitrogen, which leaves only 12 millimeters for oxygen. Such a low oxygen pressure would cause almost immediate death. Donati must have been unusually well adapted to withstand oxygen lack, and even so it is thought that he must have been in a semiconscious state, close to death. He collapsed when he landed and had to be lifted from the cockpit of the plane.

From a practical standpoint it is considered unsafe for the average person to fly much above 20,000 feet because of the limitations of present oxygen equipment, the weaknesses of human nature, and the possibility that the oxygen supply may fail. Flights at greater altitudes become increasingly hazardous; it is doubtful if anyone should go higher than 38,000 feet in an open cockpit plane.

Summary

Some of the more important points in the foregoing discussion may now be summarized. These begin with the fact that practically a normal partial pressure of oxygen in the lungs must exist if the individual is to get enough of this very necessary substance. As a person ascends to higher levels the partial pressure of oxygen falls and at about 5000 feet above sea level the first symptoms of anoxia, or oxygen lack, may appear. It must be kept in mind at all times, however, that individuals vary greatly in their tolerance of anoxia. In some cases symptoms at 5000 feet may be relatively minor.

Above 15,000 feet signs of mental and physical failure are in evidence if oxygen is not supplied from some artificial source. Consciousness usually is lost at heights of between 18,000 and 25,000 feet, and this indicates that death is near. Some people also develop a chronic type of altitude sickness, brought on by repeated exposure.

The use of good oxygen masks necessarily alters the case. If these are provided, the flier at 33,000 feet has about the same partial pressure of oxygen in his lungs that would exist at sea level. But 40,000 feet is about the limit of safety for many people, because at this height partial pressure of oxygen has fallen markedly. It is true that men have flown to greater altitudes, but we are here talking about the *average* case when an oxygen mask is employed. Even when an oxygen mask is used, partial pressure of oxygen drops to zero at about 51,000 feet.

4

OTHER PRESSURE AND TEMPERATURE EFFECTS

IN CHAPTER 3 the effects of changing pressures were discussed only in relation to the problem of oxygen supply at high altitudes. In continuing this study let us now consider some other results of pressure changes upon the human body.

Mechanical Effects of Pressure Change

Caisson disease. Long before flying became a common experience, certain results of suddenly altered air pressure were well known. A number of disorders affecting men who worked under several atmospheres of pressure were described as *caisson disease* or the "bends." [1] In constructing the foundations of a bridge, for example, a compressed-air caisson is often used as a work chamber. In order to keep the water out, air pressure within the caisson used for underwater work must be increased one atmosphere, or about 15 pounds per square inch, for every 33⅓ feet the caisson is submerged below the surface.

Water has great weight compared with air; even at moderate depths its pressure increases up to two atmospheres. At a depth of 100 feet a worker is subjected to a pressure of 60 pounds per square inch. If the caisson is lifted too quickly, the worker, accustomed to high pressure, may exhibit a number of symptoms, such as deafness, pains in the muscles and joints, difficult breathing, vomiting, paralysis, fainting, and sometimes sudden death. Deep-sea divers, who must often work under conditions

[1] Although the term *bends* is often taken to mean the same as *caisson disease,* it should be restricted to mean pains in the arms and legs, usually in the region of the joints. *Compressed air illness* is a modern term synonymous with *caisson disease.*

of very high pressure, are even more subject to the same hazards.

When the human body is exposed to compressed air for any length of time, more than a normal amount of nitrogen enters the blood stream and the tissues of the body. If pressure is suddenly released, nitrogen comes out of the tissues and enters the blood stream in the form of bubbles. These bubbles may block the normal flow of blood and press upon nerve centers to produce the effects of caisson disease.

As people grow older they often become more susceptible to caisson disease. Studies have also shown that those least likely to be affected are lean men. The reason for this is given on page 68.

Preventing caisson disease. If pressure upon a diver is reduced gradually, nitrogen bubbles do not form in his blood to any great extent. Rather, the gas comes out of the blood and tissues slowly and is safely removed by the lungs. For this reason the practice of bringing up divers by stages and allowing them to remain at each level for a period of time was formerly followed. This method served to prevent caisson disease, but it was time-consuming and it sometimes left divers in cold water longer than was either comfortable or safe.

In recent years a better way of reducing pressure (decompressing) has been worked out. It is based upon the use of decompression tanks or chambers. A diver, for example, is brought up from a given depth with no delay. Before nitrogen bubbles have time to form in his blood, he is put in a chamber in which the pressure is about the same as that under which the diver has been working. The decompression chamber may be provided with light and heat for the sake of greater comfort. Air is allowed to escape from it little by little, so that the pressure is gradually returned to normal.

Pressure and deep-sea fish. The mechanical effects of pressure change are well known to those who have studied fishes of the deep sea. The bodies of such animals are often filled with gas that has been under compression down in the depths. When a fish is brought to the surface, there is nothing to prevent expansion of this gas. The result is that the internal organs gush forth, and that the body may be broken up until it is hardly recognizable. This of course is not true of all species, because some of them have special adaptations that make toleration of considerable pressure change possible.

Pressure changes in flight. We have already noted that fliers encounter pressure changes, but they are of a somewhat different nature. When a diver goes down into the water, pressure upon him is increased.[2] On the other hand, the aviator is going into a region of *reduced* pressure as he ascends.[3] The total effect upon him is less likely to be dangerous, for one reason because the speed at which he rises is often moderate, so that there is time for his body to make necessary adjustments. Atmospheric pressure is reduced to about one half at 17,962 feet, one fourth at 33,705 feet, one sixth at 42,151 feet, one eighth at 48,230 feet, and one tenth at 52,909 feet. Let us assume for the moment that a flier might go to an altitude of 42,151 feet (some people could, with the aid of oxygen equipment). At this point the atmospheric pressure would be down to one sixth of its sea-level value. It would be about 2.3 pounds per square inch, and this would mean a reduced pressure upon the whole body of about 20 tons.

It might seem that such a tremendous decrease in pressure on the surface of the body would cause it to explode. However, this does not happen for several reasons. In the first place, the ascent is usually slow enough so that much of the gas in the digestive tract passes out before the flier reaches the higher altitudes. Furthermore, the tissues do not swell to any great extent because the body, which is about 66⅔ per cent water, reacts to changes in pressure as though it were made entirely of this liquid. Therefore the body neither expands nor contracts as a result of pressure changes, but such changes are transmitted instantly throughout it.

This is not to say, however, that the body escapes injury when normal pressures are lessened. Let us turn now to consideration of some things that may happen.

Effects on the stomach and the intestines. The stomach and intestines of man usually contain a relatively small amount of gas. This gas consists of a mixture of air that has been swallowed and other gases released from foods that are being broken down. At about 53,000 feet, when the atmospheric

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[2] Both the pressure of the water and that of the air supplied to the diver.
[3] If we assume that a pressure cabin is not used.

pressure has been reduced to one tenth its normal value, gases of the digestive tract expand to ten times their original volume. The effect of this expansion depends upon the amount of gas present and also upon the rate at which the flier has gained altitude. If the ascent has been rapid, the intestines become greatly distended and exert pressure in all directions.

Now the abdominal wall offers considerable muscular re-

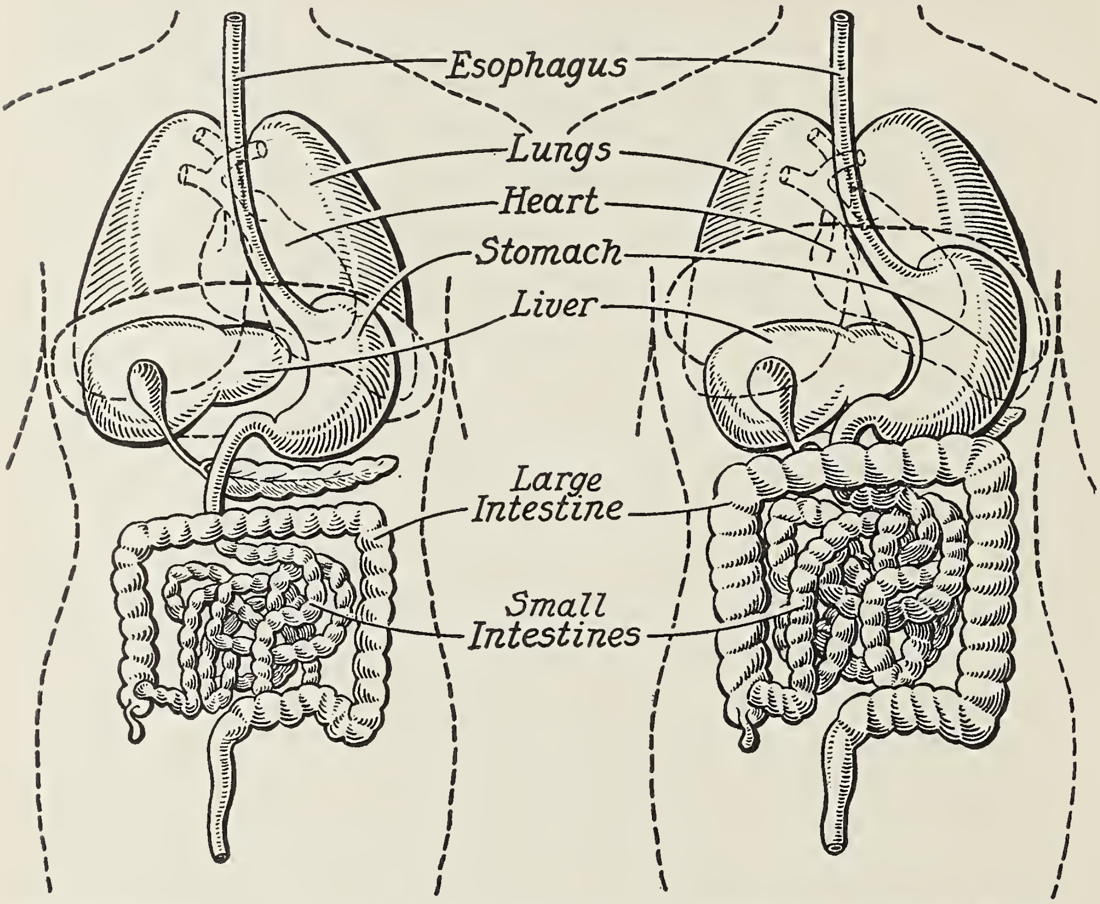

Fig. 20. How expanding gas in the digestive tract causes crowding of organs in the thorax

sistance to the expanding digestive organs. The floor of the abdominal cavity is surrounded by a bony structure. Therefore the pressure is directed upward toward the thorax. The liver is raised and pushes against the diaphragm. This decreases the potential breathing space in the thorax (see Figure 20). The air capacity of the lungs is further reduced because the downward movement of the diaphragm is partly blocked by the counterpressure of the expanded digestive tract. The heart may also be crowded by the general pressure put upon the thorax.

In spite of all this interference with the action of the lungs and the heart, normal persons are not likely to suffer seriously. In some cases, however, crowding of the organs in the thorax may result in fainting. In any event there is likely to be discomfort and even pain. In the case of a person who is not in good health, the result may be very different. If he suffers from disorders of the heart or lungs, excessive abdominal gas pressure may be dangerous. Such an experience would also be risky for people having ruptures, abdominal wounds of any kind, ulcers, or obstructions of the intestines.

The foregoing facts suggest that the flier should choose his food wisely and not eat heavily before going on a long flight. In other words, everything possible should be done to reduce the formation of gases. Certain items, including navy beans, cabbage, onions, strongly flavored and spiced dishes, and heavy, fried foods, should not be eaten in large amounts. Again, however, individual differences must be taken into consideration; the food that causes gas to form in one person may not affect another.

Effects on respiratory acts. At high altitudes the atmosphere, as we know, is much less dense than at sea level. We sometimes say that the air has become "thinner." A number of effects upon functions related to respiration may be noted. For example, the pitch of the voice becomes higher at about 25,000 to 30,000 feet. A greater volume of air is required to vibrate the vocal cords; hence several breaths may be needed to say what could be said in one breath at sea level. Hoarseness is developed after talking for only a short time. This hoarseness, combined with changed pitch of the voice, may make radio communication difficult. It is an interesting fact that at 25,000 feet it is impossible for one to whistle.

At altitudes of 30,000 feet or more the respiratory acts, such as coughing and sneezing, are greatly changed. Normally the sudden forcing of a large quantity of air through the air passages of the body requires strong contractions of the chest muscles. But the light air of high altitudes rushes out of the lungs with a small amount of resistance, and only a little back pressure develops. Because the chest muscles do not meet the usual resistance, one feels as though the chest walls had suddenly caved in. Moreover, if a cough is due to some irritating substance in the bronchial tubes, the material is removed, if at all, with great difficulty. This is because the thin air is ineffective in sweeping mucus or other material out of the air passages. There may therefore be no relief from the cough until the flier descends to lower levels.

All this suggests that persons with respiratory troubles should not fly at high altitude when they may be subject to prolonged spells of coughing. One exception would be in the case of those who suffer from asthma, for they appear to get relief in the rarefied air.

Effects on the ears. Even one of the early balloonists complained that he suffered severe ear pains while in flight. Now it

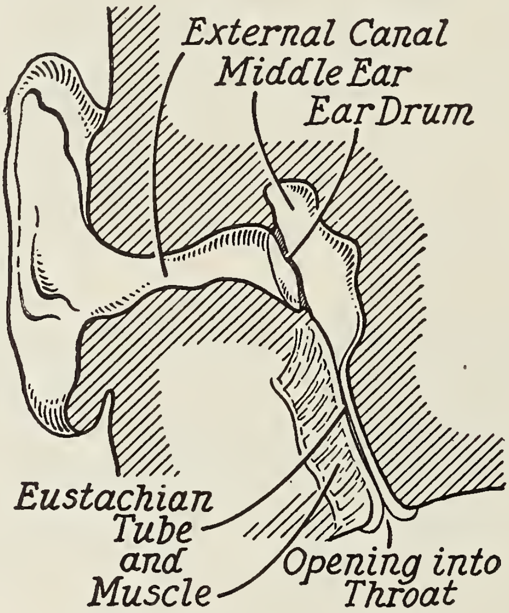

Fig. 21. Diagram of the ear

is generally known that the middle ear presents a special problem to those who go up into the air. The middle ear is an air-filled space lying between the outer ear and the inner ear, as shown in Figure 21. The Eustachian tube[4] is a slitlike tube that connects the cavity of the middle ear with the back of the throat. It is often collapsed, but it should be able to open and permit the passage of air to or from the middle ear. When one ascends to high altitudes, the expanding air[5] in the middle ear produces considerable pressure, due to the fact that the Eustachian tube is normally closed, so that air cannot escape. About

[4] The Eustachian tube is so named because it was first described by an early Italian anatomist named Eustachio.

[5] It expands because pressure has become reduced on the *outside* of the eardrum.

15 millimeters of pressure, however, is enough to force open the Eustachian tube and allow air to pass out of the middle ear and thus temporarily to end the discomfort. As a plane continues to climb, pressures will now and then be built up to a point sufficient to open the Eustachian tube again. Each time that they are there is an annoying "click" in the middle ear when the pressure is relieved and the bulging eardrum snaps back into place (see Figure 22).

During descent it may be even more difficult to keep the pressure in the middle ear about the same as that on the outside.

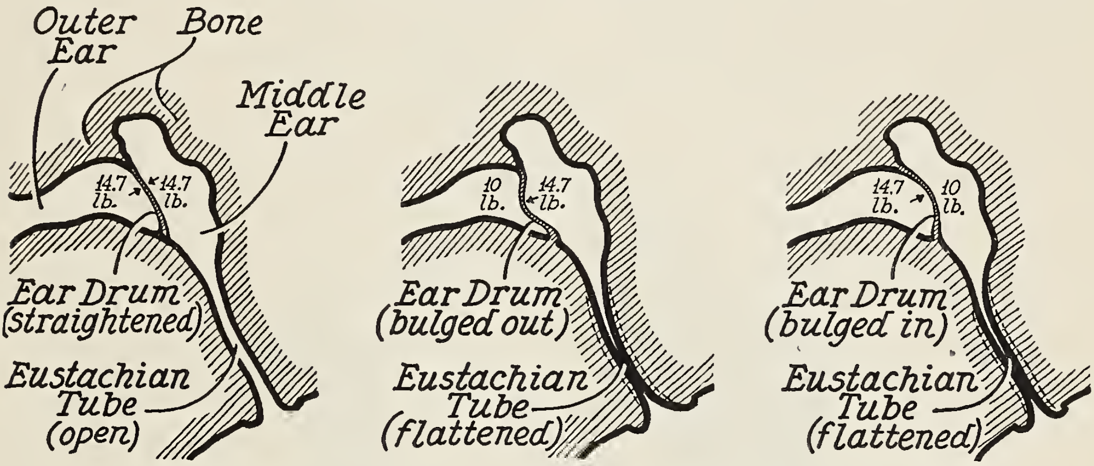

Fig. 22. Effect on the eardrum of changing air pressure

This is because the Eustachian tube acts like a valve that allows the air to pass readily in one direction only, that is, from the middle ear to the back of the throat. When the airplane descends the pressure relationships reverse themselves; the pressure is less in the middle ear than it is on the outside. This means a negative pressure (partial vacuum) in the middle ear, which causes the walls of the Eustachian tube to be drawn closely together. Therefore special means must be used to open this passageway and allow more air to enter the middle ear. This can be accomplished by yawning or swallowing.

If not too great a negative pressure has been built up, the Eustachian tube can usually be opened by either of the methods just suggested because in either case the Eustachian muscles are caused to contract. Another way to force open the Eustachian tubes is to close the mouth, pinch the very edges of the nose shut, and blow (not too hard). If the negative pressure in the middle ear is so great that the Eustachian tube cannot be opened by any of these means, then relief can always be obtained by ascending to a higher altitude. Usually, however, a reasonably slow descent with frequent swallowing or yawning will prevent any real distress. The average person swallows without conscious effort about every sixty seconds,[6] and with a rate of climb or descent of about 200 feet per minute there should be no discomfort. This rate, however, is often exceeded in certain kinds of military experience. Chewing gum, drinking, or eating increases the swallowing to intervals of from about two to twenty seconds.

Fig. 23. A special device used for opening the Eustachian tubes

A commercial airline has developed a device for opening the Eustachian tubes when the negative pressure (partial vacuum) in the middle ear becomes so great as to overpower the Eustachian muscles. This device is shown in Figure 23. As will easily be understood from the illustration, the user holds one side of the nose closed while filling the little rubber balloon with air from the other nostril. As the bag fills a pressure of as much as 18 millimeters of mercury is developed in it. This pressure forces the Eustachian tube to open, and the typical clicking

[6] The intervals between swallowing of sleeping individuals decrease in length and present a serious problem. Children seem less subject to unpleasant effects than adults. On sleeper planes it is advisable to waken passengers every time the plane descends from any considerable height to prevent injury of the middle ears.

sensation is felt in the ear. If only one ear is relieved, the bag may be shifted to the other nostril and the process repeated. In some instances the Eustachian tubes refuse to open even when the balloon has been inflated. If this proves to be the case, swallowing when the balloon is fully inflated will usually bring good results. This is because air pressure combines with muscular action to open the Eustachian tubes.

This same company, in addition to using the equipment just described, has adopted the standard practice of distributing Benzedrine inhalers to passengers of their planes. Benzedrine, because of its constricting effect on tissues, causes sufficient shrinkage of mucous linings to relieve many people when it is inhaled. If the passengers suffer considerable ear distress, a liquid preparation known as Auralgan may be dropped into the external canals of the ears with good effect.[7]

When one is suffering from a head cold the Eustachian tubes may be swollen shut. Therefore persons who have such colds or who suffer from any other disorder that temporarily or permanently closes the Eustachian tubes should not fly to high altitudes.

A descent of 10,000 to 15,000 feet without ventilation of the middle ears will usually cause rupturing of the eardrums. Ruptured eardrums will heal in time, but repeated damage to the middle ears, even though the drums are not ruptured, may result in a partial loss of hearing. Due to inability to open their Eustachian tubes, some fliers suffer a temporary ear injury that results in moderate deafness for several hours.

Effects on sinuses. Like the middle ear, some of the sinuses are air-filled spaces located in hollow bones of the head. They present problems in flight similar to those caused by the middle ears. Figure 24 shows a diagrammatic sketch of these sinuses.

Each sinus is lined with a delicate membrane that is continuous with the lining of the nose. During a severe head cold the inflammation often extends from the nasal lining to the lining of the sinuses, giving rise to headaches and other symp-

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[7] One of the commercial airlines that was using the self-Politerization (rubber balloon) equipment has discontinued its use because of the possible injury to persons suffering from sinus trouble. Some doubt has been expressed about the advisability of using inhalers because of potential danger to passengers who have heart trouble.

toms. The lining of healthy sinuses secretes a moistening fluid that drains through small passages into the main cavity of the nose. Under normal condition air passes freely through these passages into and out of the sinuses.

We have seen that pressures change with ascent and descent. If air is able to pass readily to and from the sinuses, no ill effects are experienced. When the passageway to one of these sinuses becomes blocked, however, as sometimes happens due to growths in the nose or the effects of a severe cold in the head, an excess of pressure or lack of pressure (partial vacuum) is

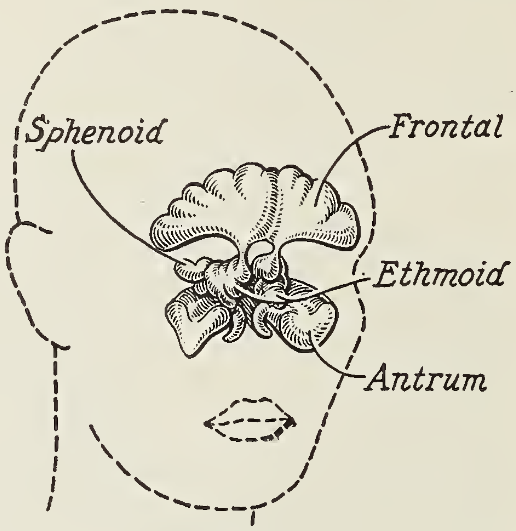

Fig. 24. Some sinuses in the head region

produced in the sinus itself. The resulting pains may be almost unbearable and may seriously interfere with the efficiency of a pilot. Of course a factor that in any way lessens the pilot's efficiency deserves respectful consideration.

Effects on body fluids and tissues. A condition called *aeroembolism* is caused by the liberation of gas bubbles, principally nitrogen, in the spinal fluid, blood, and tissues, due to decreased air pressure in high altitude flight, with a resulting tendency of the nitrogen to leave the body. It is similar to what happens when a deep-sea diver is decompressed too rapidly.

In the normal individual, fluids, fats, and body tissues are saturated with nitrogen, which has been carried to them by the blood stream from the air. Nitrogen, in contrast to oxygen, is an inert gas as far as the body is concerned. It is not used by the tissues, but it does no harm unless it begins to escape at a rapid rate. One investigator gives the following figures for the normal (sea-level) nitrogen content of a man weighing 155 pounds: blood 301 cubic centimeters, fat 530 cubic centimeters, bone 0 cubic centimeters, and a residue of 435 cubic centimeters. It is interesting to note that, for a given mass unit, fat will dissolve about six times as much nitrogen as will blood; this is a cause of increased difficulty for the overweight individual, as will be explained later.

With the decreasing pressure in ascent, the internal partial pressure of nitrogen gas of the body reaches a point at which it is above that of the nitrogen in the lungs. If it becomes about double the normal partial pressure of nitrogen in the body, the gas will come out of solution in the form of bubbles. These

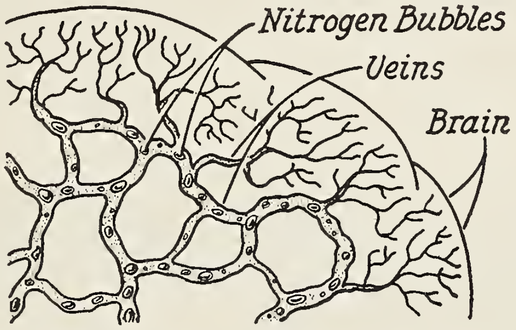

Fig. 25. Nitrogen bubbles in veins of the brain

bubbles pass into the blood (see Figure 25) and eventually are given off through the lungs.

It has been found that nitrogen bubbles appear in the spinal fluid at 18,000 feet, while those in the blood and body tissues usually are present at about 30,000 feet. They are the cause of aeroembolism, attacks of which are fairly common at altitudes of 33,000 to 35,000 feet. The slower the ascent, the greater the delay in the development of symptoms. The higher one goes, the shorter the time before symptoms appear. When first formed, the bubbles are microscopic in size and are therefore no great menace. But as time goes on they tend to join and become larger and larger, until they reach the size of a pea. Objects of such size pass through large blood vessels without difficulty, but when they reach a vessel that is small they lodge in it and block it as effectively as a stone might. The circulation is then stopped locally, and the blood supply is shut off from a certain part of the body.

Blocking the supply vessels of the heart may cause heart failure, while blocking of the circulation to the lungs brings about a condition in which the little air sacs of the lungs fill with fluid, as in cases of pneumonia. If an extensive area of lung tissue is involved, one may literally drown in his own liquid. While the irritation of the lungs causes coughing, the coughing is not effective in getting rid of the fluid because of the thinness of the air, as previously explained.

The symptoms of aeroembolism, which are the same as those of caisson disease, include joint pains and paralysis, as well as the embolism just described. The pain and paralysis develop when the nervous system becomes involved. Increased pressure of gas bubbles in the cerebrospinal fluid, although it may be considerable, is not thought to produce serious effects because there is no opportunity for the gas to escape as it does from the blood through the lungs. The disorders of the nervous system that do occur are thought to be due to a blocking of blood vessels that supply an affected part. Pains similar to neuritis may develop, and in some cases paralysis occurs and may come on without warning. Any part of the body is likely to be affected, and death may take place if a vital organ is involved. Probably the greatest danger comes from the possibility of a pilot's becoming helpless and losing control of his plane.

It has been observed that different people, even with similar body builds, are not equally susceptible to aeroembolism under the same conditions. Fat persons are generally more likely to suffer attacks than are thin people because of the greater amounts of nitrogen gas contained in fat. One of the leading aviation physiologists recommends that lean pilots be selected for high altitude flights of 35,000 feet.

Internal boiling of the body. A liquid can be made to boil by raising its vapor pressure to that of the atmospheric pressure on the liquid surface. This is most frequently accomplished by heating the liquid, but it can also be caused by lowering the atmospheric pressure or by a combination of these methods. The variation of the boiling point with pressure may be demonstrated by enclosing water to be boiled, reducing the air pressure on the surface, and noting the temperature at which boiling takes place. The pressure within a flask of water can be so reduced that the water will boil when the flask is held in the hand; in other words, the liquid is made to boil at body temperature.

The body temperature, which is 98.6° F., has a vapor pressure of 47 millimeters of mercury. Thus it will be seen that, when an altitude is reached at which the atmospheric pressure is 47 millimeters or less, the body fluids will boil. At approximately 63,000 feet such a pressure exists. One exposed to this pressure would literally suffer internal boiling.

In general, there is an enormous increase in volume on vaporization. For example, one gram of steam at 100° C. occupies 1671 cubic centimeters while one gram of water occupies

Courtesy The Williams & Wilkins Company

Fig. 26. The upper picture shows a rabbit at sea level, and the lower picture shows the same animal at an altitude of over 63,000 feet. The increase in size is due to the boiling of body fluids.

approximately 1 cubic centimeter. Therefore an animal becomes greatly swollen by steam (water vapor) when exposed to a high enough altitude to cause the fluids of its body to boil. The effects of such internal boiling are shown in Figure 26. The result of course is sudden death.

In view of the fact that it is unwise to go to altitudes above about 40,000 feet, even with oxygen, it might seem that the boiling of body fluids at high altitudes is of no practical importance. This assumption, however, is not necessarily true, as will be clear from the discussion of pressure cabin failure later in this chapter.

Prevention of aeroembolism. Keeping out of the higher altitudes (that is, keeping below 30,000 feet) should eliminate the dangers of aeroembolism. However, this is a rule that a military aviator may not be able to follow.

If the rate of ascent is no greater than 78 feet per minute, the nitrogen will pass out of the blood into the lungs rapidly enough to prevent the formation of gas bubbles. Obviously this is not a practical preventive method, for such a slow ascent is too time-consuming. When an air raid is sounded, the chief purpose of a fighter plane is to reach a high altitude as quickly as possible and to strike the enemy before he can accomplish his job of bombing. For military effectiveness against an enemy plane with a cruising speed of 300 miles per hour at 30,000 feet, a fighter plane must be able to reach this altitude very rapidly, since in fifteen minutes the enemy bomber will be 75 miles nearer to its target. Most of the modern airplanes are able to climb 1000 feet per minute; in fact, some can reach an altitude of 15,000 feet in ten minutes.

The most practical method of preventing aeroembolism is to eliminate some nitrogen from the body by breathing pure oxygen before and during ascent. Breathing 100 per cent oxygen washes nitrogen out of the blood quite fast. If the circulation of the blood is increased through exercise, nitrogen removal is hastened. For instance, symptoms of aeroembolism are not likely to appear even in rapid climbs to 40,000 feet if pure oxygen is breathed for forty-five minutes or longer while one is at rest or if 100 per cent oxygen is breathed while one is walking on a treadmill at the rate of two miles per hour for twenty minutes or longer.[8] This method of inhaling pure oxygen strikes at the cause of aeroembolism by getting rid of the nitrogen, which produces the offending gas bubbles in the body.

The simplest treatment for aeroembolism is to descend to lower altitudes when the first effects are observed. Coming

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[8] More studies are needed to determine the exact rate of nitrogen elimination while one is breathing pure oxygen under varying conditions and also the amount that must be eliminated to prevent the formation of dangerously large nitrogen bubbles in the blood.

down only a few thousand feet is all that may be necessary if the bubbles in the tissues are small. The increase in pressure at lower levels results in a reduction in the size of the nitrogen bubbles that are causing distress; but relief of symptoms does not necessarily mean complete removal of the bubbles, for this is a slow process. One experiment showed that bubbles stayed in the blood stream of a goat for two days and in the spinal cord ten days after return to normal pressure. The bubbles probably remain in the spinal fluid longer than in the blood because they have less opportunity to escape. For the same reason bubbles appear in the spinal fluid before they do in the blood.

Early attempts to prevent the ill effects of low pressure. All the dangers and discomfort experienced from decreased pressures at high altitudes can be avoided if a sea-level pressure in the cabin of a plane is constantly maintained. Maintaining such a pressure makes oxygen equipment unnecessary, for as long as the air breathed has a normal pressure the partial pressure of its oxygen will also be normal and no oxygen lack will occur.

The idea of a pressure cabin became a reality in 1920, when the U. S. Army Air Corps replaced the cockpit of one of its pursuit airplanes with a steel tank. This tank had a removable cover that served as a door to the so-called cabin. There was a sealed glass port to enable the pilot to see outside. A supercharger was used to provide pressure for the cockpit, and there was also a hand-controlled exhaust valve, by means of which the pressure was to be kept from rising above normal.

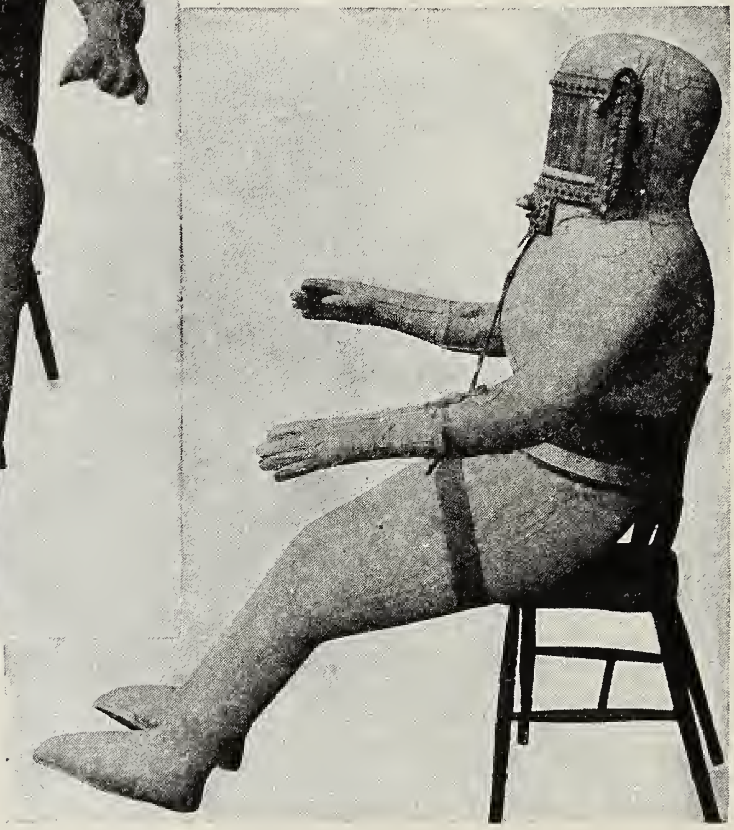
The first flight of this pressure cabin airplane was made June 8, 1921. It was not only unsuccessful, but it also almost ended in tragedy, because the amount of air entering the cabin from the compressor was more than that which could be discharged through the exhaust valve. As a result the pressure became so great that the temperature increased to about 150° F. Although suffering intensely from high pressure and great heat, the pilot managed to land the airplane safely.

Attempts to solve the problem continued. In 1933 Wiley Post experimented with a pressure suit; and in 1934–1935 he made several high altitude flights with what he called his stratosphere suit, but no records of his results have been found. The fact that Post discarded his pressure suit and never did further work on the idea would, however, indicate that he was not very favorably impressed with its possibilities.

Pressure suits. In 1936 a member of the British Royal Air Force, using a pressure suit, made a new international record for airplane altitude—49,944 feet. Then in 1937 Flight Lieutenant Adam, wearing the same suit (see Figure 27), made another new record of 53,937 feet.

Fig. 27. Two pictures of the British Royal Air Force oxygen-pressure suit that was used in breaking the world's airplane record for high altitude

Courtesy The Williams & Wilkins Company



The British suit illustrated in Figure 27 was made of a rubberized material. The helmet, which was of the same substance, contained a large curved window. The suit was kept inflated with an oxygen pressure of two and a half pounds, about that of the surrounding atmosphere. The chief shortcomings of such a suit are that it cannot withstand high pressure, it seriously interferes with movement and vision, and it is about as clumsy an outfit to put on and take off as the armor of a knight.

From the foregoing it can be seen that the pressure suit, as developed up to the present time, has definite limitations. It possesses some advantages over a pressure cabin, however, chief of which is the fact that it requires no modification of existing airplanes. Also it is comparatively light, and it does not present as large a target in military aviation as would a cabin.

Pressure cabins. In 1937 the Lockheed Aircraft Corporation completed the first successful pressure cabin airplane ever built for the U. S. Army Air Corps. This development of the first satisfactory pressure cabin plane to be flown anywhere in the world won the Collier Trophy for the Army Air Corps. Since that time the use of pressure cabins has gained rapid acceptance, and now several manufacturers in this country are building pressure cabin planes for commercial use. Sleeper transports with these cabins have gone from coast to coast in about twelve or thirteen hours. The passengers sleep as well as they would in their own homes insofar as pressure is concerned.

The obvious advantages are that such airplanes make unnecessary the use of oxygen equipment and do away with all of the bad effects that may develop from low pressure at high altitudes; in short, they provide ideal flight conditions for the flier. The pressure cabin airplane therefore bids fair to be the ultimate solution of the problem of high altitude flight, at least insofar as commercial transportation is concerned. It has been predicted that within the next five or ten years all airlines engaged in high altitude (15,000 to 20,000 feet) flying will be using pressure cabin equipment.

A pressure cabin consists of a sealed (airtight) space into which air from the outside is forced by means of some type of compression. If air were continually forced into an airtight cabin, however, it is obvious that intolerable pressures would soon develop. Moreover, the cabin would become unbearably hot, for as incoming air is compressed its temperature is raised. Thus an exhaust valve is necessary to permit the escape of enough air so that a uniform pressure is maintained. The flow of air through the cabin which this arrangement provides keeps it well ventilated. Ideally the pressure in the cabin should be that which exists where the plane takes off and lands.

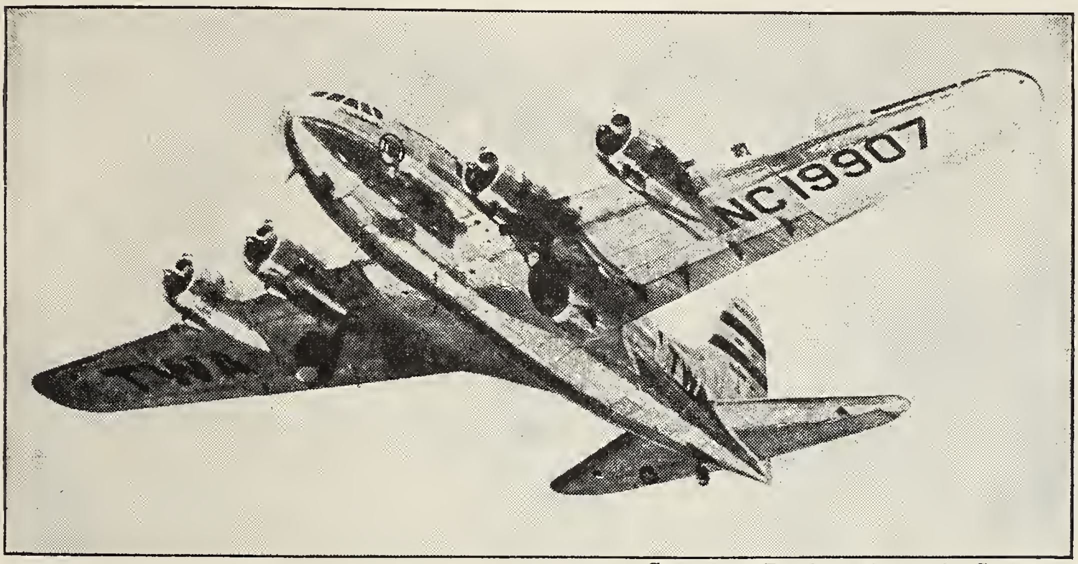
Some of the most obvious disadvantages of the pressure cabin are that it increases the cost of aircraft, adds considerable weight, and provides a large target in military operations. Then there is the danger of cabin failure. This might result from an

Courtesy The Williams & Wilkins Company

Fig. 28. Gondola of the balloon Explorer II

air leak or from some mechanical failure of the compressor. If a leak developed in the cabin, the occupants would be exposed to the pressure existing at the altitude at which the plane was flying. If cabin failure happened above 30,000 feet, it is easy to imagine the serious effects that would soon follow; the individual would suffer from oxygen lack and aeroembolism, to say nothing of the effects on the middle ear, sinuses, and digestive tract. Above 63,000 feet cabin failure would result in boiling of the body fluids and instant death.

The heights mentioned have actually been reached by man in modern aircraft. Stevens and Anderson made an international altitude record of 72,395 feet on November 11, 1935. This was made possible by the use of a pressure gondola attached to a balloon, the famous *Explorer II* (see Figure 28).



Courtesy Boeing Aircraft Company

Fig. 29. The world's first high altitude commercial airliner

The hazards that are possible in pressure cabin flight are not likely to be realized (except in military operations), as brief consideration of the subject will show. In civil flying there is little reason for ascending to 30,000 feet; and the worst that could happen below that height, at the usual cabin pressures, would be acute oxygen lack. Of course in the case of cabin failure at high altitudes people suffering from heart or lung ailments might suffer more serious injuries. All these dangers to health would be minimized by the fact that a pilot could probably descend several thousand feet before the passengers would begin to experience the bad effects of high altitude. Furthermore, an emergency supply of oxygen could be used during the time necessary to descend to lower and safer heights.

The Boeing Stratoliner shown in Figure 29, which is a transcontinental pressure cabin plane, flies at 14,000 to 20,000 feet, which is of course in the substratosphere rather than the stratosphere. When the Boeing Stratoliner is traveling at an altitude of 16,000 feet, the pressure in the cabin is equal to that at an 8000-foot level. In case of compressor failure there is an auxiliary compressor that can be turned on. The exhaust valve is an automatic device, but it can be operated by hand if it gets out of order. Thus it may be seen that great precautions are taken to insure the safe operation of the pressure cabin.

In military aviation when it is desirable for planes to fly above 30,000 feet, the effects of cabin failure from any cause might be more serious and the risk of aeroembolism in particular would be greater. However, the lag in actual bubble formation would probably give the fliers time to descend below 30,000 feet. Flights above 40,000 feet in pressure cabin planes would be dangerous if there were strong chances of cabin failures, for there are no protective measures available for such altitudes.

It seems clear that the pressure cabin is the best solution to the problems of low pressure flight from the standpoint of the passenger. It does away with the trouble of using oxygen, and it prevents all the unpleasant effects that are due to reduced pressures. From the standpoint of airlines, greater speed and economy can be obtained by substratosphere flight provided that the trips are of sufficient length. If present trends continue, there is good reason to believe that practically all transcontinental and transoceanic airlines will soon use pressure cabin airplanes. Commercial transport companies will probably not be slow to appreciate the fact that the pressure cabin is a most important contribution to the comfort of people who travel by air. It is entirely possible that all airlines will eventually use only pressure cabin planes; until they do, the ear and sinus problems of passengers will not be solved.

Temperature Changes and Flight

The temperature at high altitudes. So far in this chapter we have considered additional results of pressure changes. Let us now give some thought to problems of temperatures that the flier encounters in the upper air. It has been pointed out that there is a decrease in temperature with increase in altitude until the base of the stratosphere is reached. From Table III it is apparent that on the average there is a decrease of approximately 1° F. for each 280-[9]foot increase in height up to about 35,000 feet. Table III is based on the standard atmosphere that

TABLE III

ALTITUDE-TEMPERATURE TABLE

Altitude in Feet	Temperature
0	59.0° F.
5,000	41.2° F.
10,000	23.3° F.
15,000	5.5° F.
20,000	−12.3° F.
25,000	−30.2° F.
30,000	−48.0° F.
35,000	−65.8° F.
40,000	−67.0° F.
45,000	−67.0° F.
50,000	−67.0° F.
55,000	−67.0° F.
60,000	−67.0° F.
70,000	−67.0° F.
75,000	−67.0° F.

has been adopted by the National Advisory Committee for Aeronautics. The standard atmosphere is the mean of summer and winter conditions over the United States at about 40° north latitude.

The fact that the temperature decreases with ascent creates a specific problem for the airman. In fact, there are few conditions in flight that cause as much suffering as does cold in an open cockpit plane or in one that is closed but unheated. Man is warm-blooded; his temperature does not normally vary more than 1° F. from the average temperature, which is 98.6° F. No clothing has been developed that affords very good protection from the cold if the temperature is less than −10° F. It will be seen from Table III that at 20,000 feet a temperature is reached which makes it difficult to protect the pilot. With military fliers commonly going to an altitude of 35,000 feet, the seriousness of the matter is obvious.

The temperatures that are met in high altitude flight can be compared only with the conditions experienced on polar ex-

[9] Usually the decrease in temperature with increase in altitude is given in round numbers as 1° F. for each 300 feet. Actually the decrease in temperature with increase in altitude depends on a number of variable factors.

peditions. It will be remembered that an altitude record of nearly 50,000 feet has been made in an open cockpit plane. The pilot probably experienced a temperature of 67° below zero.

To appreciate the intensity of cold and its biological effects on the aviator, we must also consider the speed of temperature change. In contrast with polar expeditions, the low temperatures of high altitude flight are reached in a very short time and, moreover, these flights are often started from places that are relatively warm. For example, the pilot of an interceptor plane has to put on his winter flying clothing for high altitude work before the take-off. He is soon wet with perspiration and, when the cold of the upper atmosphere is reached, he is likely to become chilled.

Table IV

DISTRIBUTION OF BODY HEAT LOSSES

Means of Heat Loss	Percentage of Heat Loss
Conduction	31.0
Radiation	43.7
Evaporation from skin and exhaled air	22.6
Inhaled air	1.2
Food, water, excretia	1.5
Total	100.0

Cooling of the body. In addition to the temperature of the air and the kind of clothing worn, a number of factors influence the cooling of the body. For instance, the amount of blood in the skin is an important factor. The larger the flow of blood in this region of the body, the greater the heat loss by radiation and conduction. A rise in skin temperature causes the blood vessels to increase in size, whereupon they carry more blood and a greater amount of heat is given off. A fall in skin temperature has just the opposite effect, for then the blood vessels constrict and less blood passes through them. Moist air conducts heat better than dry air; therefore heat loss is more rapid in a damp atmosphere. This explains why we feel chilled to the bone on cold, damp winter days. Air that surrounds the body is soon warmed; hence motion of the air removes heat from the body rapidly.

It will be helpful to consider how heat losses normally occur in analyzing the problem of protecting the body from cold. If the total heat production by a person engaged in moderate activity at room temperature is 2700 calories, then the approximate loss through different channels is as given in Table IV. It will be seen that most of this loss is accounted for by conduction and radiation. In flying at high altitudes one obvious

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Fig. 30. Winter flying suit

problem is to prevent such heat dissipation from the skin. The need is all the more acute because the flier cannot make up heat losses by physical effort, such as walking or running. Moreover, when the air is very dry, a good deal of heat passes off with the increased amount of water vapor that is removed through the lungs.

Suitable clothing. Provision of suitable clothing is the most practicable way to reduce heat losses from the flier's body. It is a well-known fact that the value of such clothing is not due to the fabric itself, but to the air that is enclosed in the spaces of the material and between the material and the body. To surround the body with a motionless layer of air would be the best way to prevent heat conduction, but this is not possible.

Furs and feathers are good protection against the cold because of the great amount of air which they enmesh. Fur consists of about 98 per cent air by volume, but it has the disadvantage of becoming matted in places where there is pressure, such as on the seat and the back. Matting causes the air to be pressed out, and the protective value is correspondingly lessened. At pressure points on his body therefore the aviator should wear materials that resist compression. Sheared sheepskin, with the wool clipped to about ⅝ inch, has been found suitable, and the United States Army Air Corps has adopted it for the protection of its flying men.

It is also noteworthy that two garments are better than one, even though the total thickness is the same in either case. Clothing should not fit tightly. On the other hand, there should be no openings through which air can readily escape to the outside. This means that flying suits should fit snugly at the collar, wrists, and ankles. Rubber or other clothing which is impermeable to moisture should not be worn, because the result is to keep moisture in the underclothing. We have seen that more heat is likely to be lost if the air next to the body is moist.

Freezing. During World War I the face was protected against frostbite by use of ointments or facial creams. Vaseline and cold creams have frequently been used. Any ointment for this purpose should not contain water, because water will freeze. To be effective, facial creams must be put on in a layer as thick as a razor blade.

Better protection is afforded by face masks. But such masks usually interfere with binocular vision, feel uncomfortable, and tend to cause fogging of the goggles at temperatures below 10° F. and to frost them below −10° F.[10] Frosting may be a serious handicap because it can reduce vision to zero.

If the flier uses a face mask, he should feel it from time to time to make sure that it is in place. Should part of the face become exposed and suffer frostbite, it should be thawed out

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[10] Unless the mask is electrically heated.

gradually by covering the affected part with the hand until it becomes warm again. If a hand begins to freeze, it may be held next to the skin in the armpit. If it has actually become partly frozen, it can be thawed out slowly in cold water. Rubbing frozen tissues is not recommended, and rubbing them with snow is especially bad. Pain usually warns the victim that hands or feet are beginning to freeze, but this may not be true in the

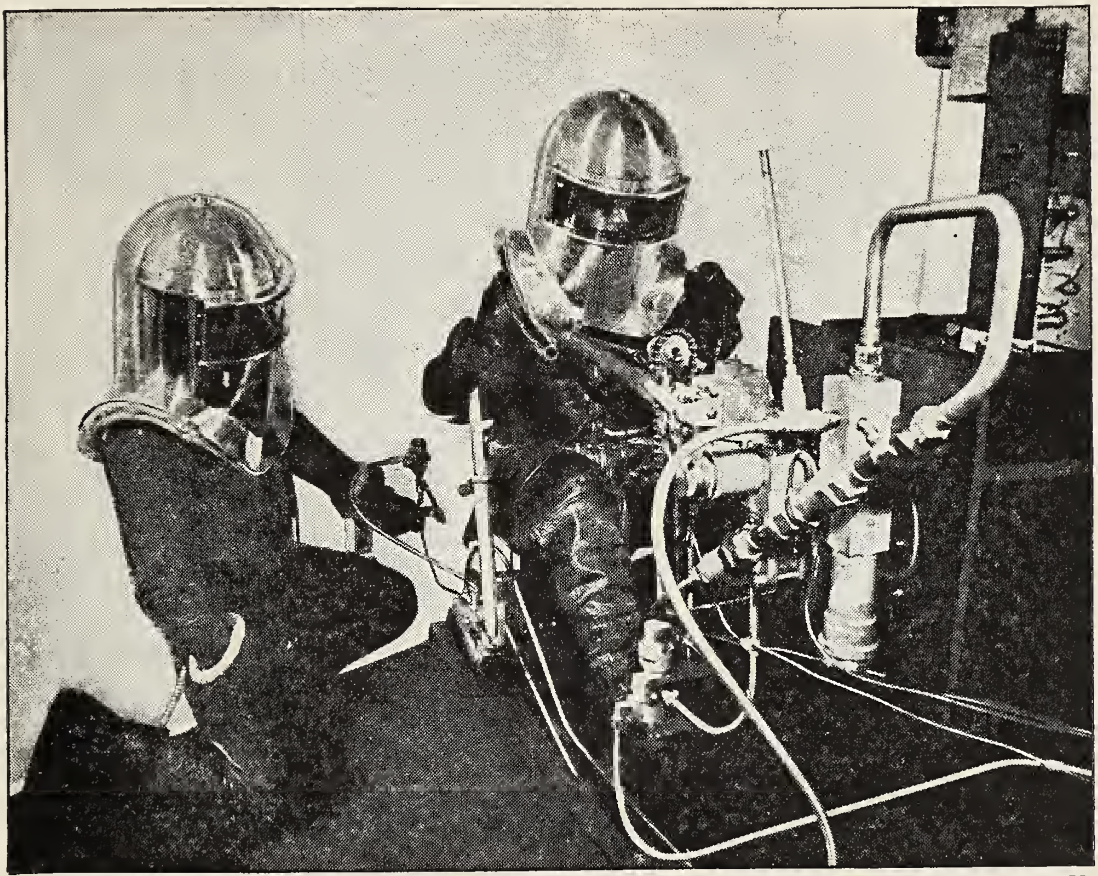

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Fig. 31. Aluminum helmets and heavy fleece-lined horse-leather suits for high altitude aircraft

case of ears, cheeks, or nose. A frozen area looks grayish white, because of ice that has formed in the tissues. Next there is a paling of the skin, followed by redness, swelling, and blistering. If the effects are extensive or serious, they call for medical treatment.

Cold and efficiency. Heavy flying clothing adds weight and considerable bulk to the pilot. Moreover, it restricts the movement of body parts that need to be free, such as the hands, fingers, arms, shoulders, and neck. One can readily see that operation of the various buttons, switches, and other gadgets on the instrument panel becomes difficult when a pilot is wearing gloves inside fur-lined mittens. Hence the pilot is likely to be wary of too much clothing, because he realizes he will be handicapped in operating his plane and will experience special difficulties if he has to "bail out" in an emergency.

As the body becomes chilled, acuteness of the sense of touch become lessened and muscular reactions are dulled. With increased discomfort, the muscles become stiff and cause clumsiness of movement. After a long flight in winter, cold feet are not very sensitive to the pressure of the rudder and the acute muscle sense that is needed for perfect landing may be lost. Of course an experienced aviator can land without using the rudders, but the fact remains that, if the pilot suffers much from cold, he may lack that exactness of sense perception that is needed for difficult maneuvers.

Cold also has a direct effect upon the mind, causing distraction, loss of morale, drowsiness, stupor, and finally unconsciousness. The relation between cold and metabolism is common knowledge. Decrease in temperature stimulates body metabolism, thereby speeding up the use of oxygen. Even shivering, which is a response that increases heat production in the body, serves to increase oxygen consumption. We have seen, however, that oxygen becomes less available at high altitudes (unless artificially provided). So cold and oxygen lack combine to make high altitude flight difficult.

As in the case of other altitude effects, some people meet the adversity of cold better than others. In general, young people are able to make more rapid adjustment to changing environmental conditions than are those who are older. It is no surprise therefore to find that they more readily withstand extreme cold.

Heated suits and cabins. In an effort to surmount low temperature difficulties, electrically heated flying suits have been used to some extent. Another partial solution of the problem is represented by the closed cabin ships, which can be warmed either by heat from around the exhaust that is conducted to the cabin or by means of steam heaters. The latter derive their heat from a tank of water that is warmed by the exhaust. However, such heating units sometimes get out of order, and they raise the additional problem of keeping frost off the windows at temperatures much below 0° F.

Summary

We have now seen that flight at high altitude brings a number of hazards in addition to altitude sickness. The lowered pressure of the substratosphere and the stratosphere may result, for example, in the development of aeroembolism. Various other disorders of lesser importance may also make their appearance. Then there is the problem of keeping reasonably warm while flying at great height and at the same time being able to do what is required of a pilot and members of the crew.

A number of attempts have been made to meet the various difficulties. For purposes of civil aviation the sealed, heated cabin, to which air is supplied at a carefully regulated pressure, solves a number of major problems provided that neither the heating system nor the pressure-regulating system fails. The use for combat purposes of airplanes with such cabins is another matter, because their all-important cabins would be fairly large targets.

Other devices, such as pressure suits, electrically heated suits, facial masks, and other forms of special clothing have been tried out and are being used to some extent. Throughout this story of efforts to meet the special problems of high altitude flight one general fact is evident. It represents what the biologist calls the law of individual difference. So far as we are concerned here, it means that some people are better able to meet the conditions of high altitude than are others.

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ACCELERATION AND THE HUMAN BODY

SPEED in itself, at least such as may be attained in our present airplanes, is harmless and has no observable effect on man. Of course at the highest rates the flier would not dare to expose parts of his body to the terrific wind blast. The pressure of air would be so great at maximum speeds that, if an arm should be held out, it would probably be broken. If the pilot should stand up in the cockpit, his head would probably be jerked backward with such tremendous force that the result might be fatal.

At the present time many of our military planes have speeds of about 300 miles per hour; and, if the past gives any indication of the future, these will be considerably increased. Even a short time ago some people were predicting what others called fantastic speeds of 600 miles per hour. As a matter of fact, unofficial records of nearly 600 miles per hour are being reported at the present time, and there is an official record that a German plane attained a speed of 469.2 miles per hour on April 26, 1939. That was the world's record at the time, but with the stimulus of war for greater and greater speed, it doubtless has been exceeded. Because of the secrecy that surrounds all war activities, however, no information of later date is available on international air speed records.

All of the speeds so far mentioned refer to level flight, but they have actually been exceeded in power dives. It has recently been reported that a dive bomber in the United States traveled 618 miles per hour in such a dive. Experts claim that speeds between 650 and 700 miles per hour are mechanical possibilities. Even these are not necessarily the top performance, for new airplane design may overcome the limiting factors of today. If rocket flight, so much talked about, ever becomes a reality, it is estimated that speeds of 25,000 miles per hour will be reached. Would such speeds be biologically injurious? There is no present reason to predict that they would.

Acceleration. *Acceleration* is defined as the rate of change of speed or direction or both. For example, if a plane acquires a speed in 11 seconds of 120 miles per hour (176 feet per second), the change of speed per second, or acceleration, is $^{176}/_{11}$, or 16, feet per second. Notice that acceleration is not the total gain in speed, but the gain per second; in this case the acceleration is 16.

The term *acceleration* is also related to decrease in speed. Thus, when one says that the brakes on his plane produce a large retarding acceleration when the plane is landing at the airport, he means that the decrease per unit of time is great. This is also called *deceleration,* or negative acceleration.

Accelerations upward or downward in the line of the pull of gravity affect the weight of an object. Thus, when an elevator starts upward with us suddenly, we weigh more and the soles of our feet press downward harder on the floor of the car. Bundles that we may be carrying weigh more during the acceleration period and our arms sag momentarily. When the car has reached a constant speed, these effects disappear.

Even though a body is moving at a constant speed in a *curved* path, it is said to be undergoing acceleration. Left to itself, it would move in a straight line. When it is caused by some force to move in a curved line it is being constantly pulled away from its normal straight-line path at a steadily increasing rate, which constitutes *acceleration.* Thus the moon is constantly falling toward the earth with an acceleration produced by the force of gravity. Because of its forward velocity it never reaches the earth but continues around it in an orbit that is nearly circular (actually an ellipse). Its speed in its orbit is very nearly constant, but it is said to be undergoing continuous acceleration for the reason given. In a similar manner, when an airplane flying at a constant speed moves in a curved path (as in making a turn or in pulling out of a power dive) the plane is being accelerated.

In pulling out of a power dive, tremendous forces act on the body; in fact, the accelerations so produced cause changes that have more sudden and dramatic results than anything else in flight. At the present time the accelerations that are of biological importance occur only during such changes of direction.

During accelerations, gravity is the unit by which we express the force acting on the body. If one weighs 150 pounds, it means that he is pulled toward the earth by gravity with a force of 150 pounds. (*Gravity* can be abbreviated to *g*. Thus an acceleration of 1 g. refers to the force that normally attracts an individual to the earth.) If we say 5 gravities, we mean an acceleration of gravity so that the total load is five times the weight. In other words, if a pilot is subjected to 5 gravities, he is pressed into his seat with a force equivalent to five times his weight. For example, a 150-pound man subjected to 5 gravities would actually weigh 750 pounds and, interestingly enough, he would also feel as though he weighed 750 pounds.

Harmless transverse accelerations. *Transverse accelerations* are those acceleration forces that act from side to side, front to back, and back to front of the body. Experiences in take-offs and landings are good illustrations of transverse accelerations. In such cases the force is not likely to be more than 1 gravity. A catapult start produces between 2 to 4 gravities, but this has no ill effect on the pilot. In take-offs and landings, to be sure, it is possible for one to be pressed back against the seat with considerable force or thrown forward dangerously hard if there is a crash landing. The injuries in such cases, however, are due to purely mechanical causes.

A special situation exists in the case of a gunner who is lying face down. He is subjected to great force from the transverse acceleration of a pull-up from a dive. The force in this case is limited to what a plane will structurally withstand, which is probably about 10 gravities. But if the body is well supported, even this experience will not prove injurious.

Positive accelerations. *Positive accelerations* are accelerations in the direction of head to foot. These are greatest in pull-outs from power dives (see Figure 32a). A sharp inside loop, as illustrated in Figure 32b, may also produce great accelerations. The effects of turning at high speed at a relatively low altitude are what makes speed flying dangerous. The time, as well as the amount of acceleration, has an important influence on the body. It is not often, however, that a high acceleration is maintained for any great interval——usually not over four or five seconds.

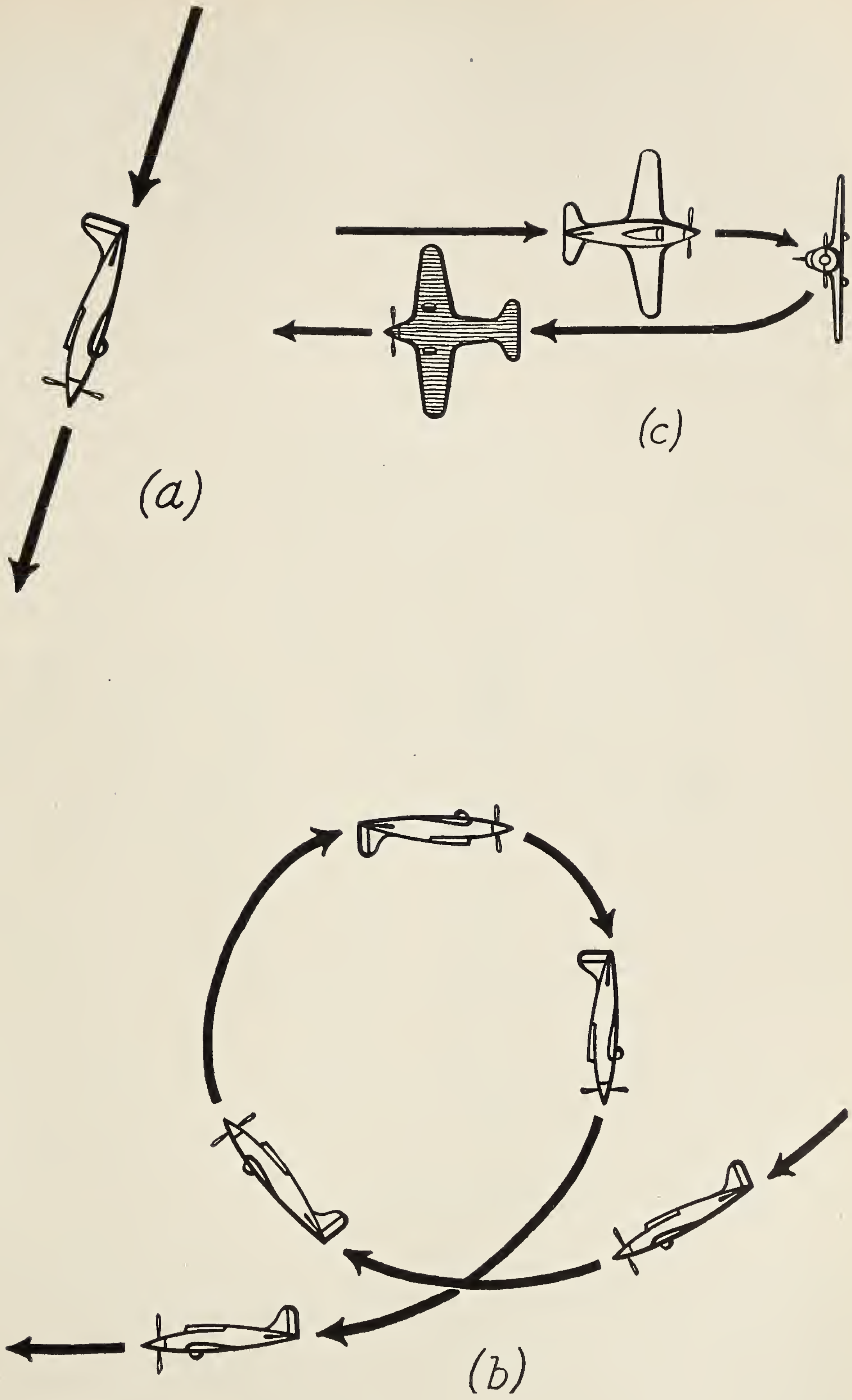

Fig. 32. An airplane (*a*) in a dive, (*b*) making an inside loop, (*c*) making a steep bank

We can illustrate the effects of high positive accelerations with the power dive (see Figure 32a). A power dive is a military maneuver in which the plane goes into an almost vertical dive with the power turned on. In bombing attacks, bombs are often released when the plane is in a dive at a speed of over 300 miles per hour and when it is only 2200 to 1900 feet above the ground. When the plane is pulled out of such a dive the amount of centrifugal force will depend on the velocity of the plane, its mass, and the radius of the curve. Centrifugal force amounts to 4.3 gravities when the speed is only 187.5 miles per hour and the radius of the curve is 500 feet. Most pilots can withstand this amount of acceleration without serious effects.

The blackout. When 5 gravities are experienced there is usually a clouding of vision, as if there were a fog before the eyes.

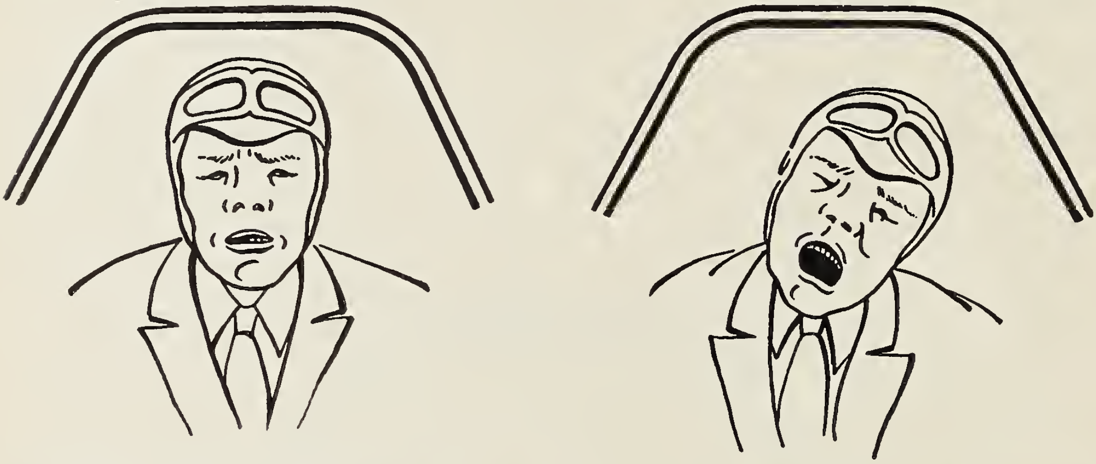

Fig. 33. A pilot (left) blacking out at 5 gravities and (right) during complete unconsciousness at 9 gravities

At 5 to 6 gravities the average pilot suffers a temporary but complete loss of sight; this is called a *blackout* or *blacking out.* It is the most dramatic effect of acceleration, and not uncommon in military experience, although it may also occur in making the sharp turns during air races.

The blackout is due to the fact that the force acting from head to feet prevents blood from being pumped by the heart to the head in normal amounts, so that there is a relative lack of blood and a drop in blood pressure above the area of the heart. Some have described the blackout as due to blood being thrown away from the head. It is generally thought, however, that there is no actual draining of the blood from the brain because there is not enough time for this to take place. But reduction of the blood flow to the brain causes a condition which is similar to that experienced in ordinary fainting.

The typical blackout lasts from only one to twenty seconds, and consciousness usually is not lost. But at 6 to 8 gravities

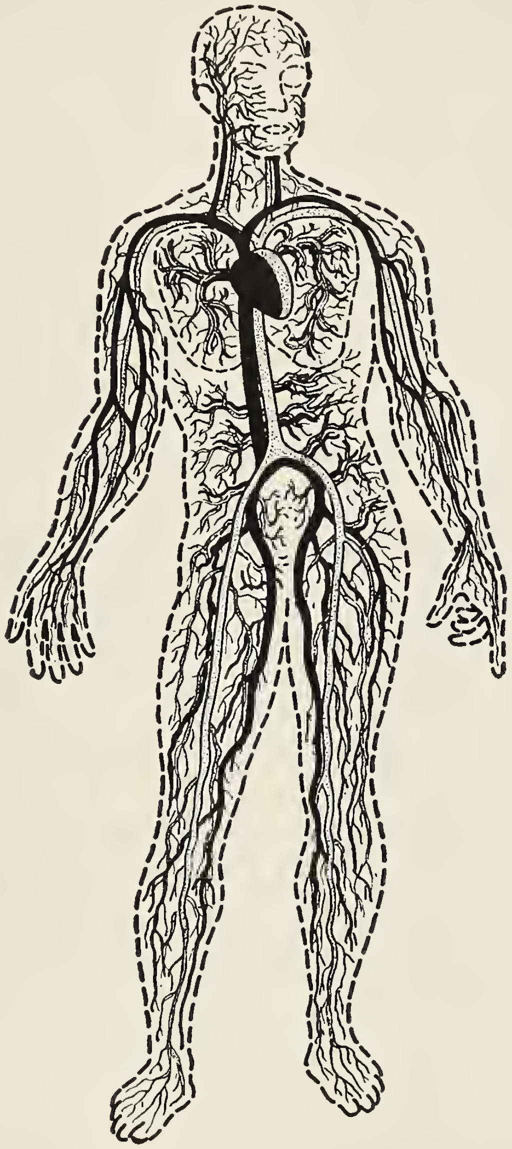

Fig. 34. The human circulatory system, with the veins shown in black and the arteries lighter

the flier does lose consciousness. Figure 33 shows the changes in facial expression of a pilot subjected to different amounts of acceleration. The limit of acceleration without blacking out is a constant figure in the case of each individual. This fact enables experienced pilots, who know their tolerance well, to "pull up and down the black curtain before their eyes" with the control stick, by narrowing or widening the curves during fast flight.

Tall individuals are more susceptible to blackout than are the short, heavy-set persons. One explanation for this is that the heart of the short pilot has to overcome less pressure in forcing the blood to the brain, because the distance that it must travel is less (see Figure 34).

Persons with high blood pressure have more resistance to blacking out than do those with low blood pressure. Contrary to what one might expect, young athletes undergoing intensive training cannot tolerate as much acceleration as when they are not in training. The resistance to acceleration is especially low in the athlete who is overtrained, because when he is in this condition he has an unusually sensitive circulatory system. Repeated exposures to accelerations seem to lower, rather than to increase, one's resistance to blacking out. Loss of general physical well-being because of fatigue also increases susceptibility.

Although blacking out lasts for only a few seconds and the victim usually does not experience anything more serious than a slight mental confusion afterwards, the results may be disastrous. In combat, for instance, a few seconds of helplessness may decide the result, for a few seconds is all that is needed to shoot down a plane.

Methods of preventing the blackout. The various methods used to prevent blackouts will be better understood if one has in mind a clear picture of the human circulation. Figure 34 shows in diagram the arterial and venous systems. It will be noted that the largest blood vessels run parallel to the long axis of the body; in other words, they connect the heart with the head region on the one hand and the trunk and lower extremities on the other. Therefore, as has been indicated, centrifugal force acting in the direction of head to foot tends to slow, if not prevent, the flow of blood to the head, but it hastens the flow toward the feet. As a result, the heart is working against the forces of acceleration in pumping blood to the head.

Then, too, the venous blood from the lower part of the body is prevented from returning to the heart in the normal way. Thus there is a great reduction in the return of blood to the heart, with the result that the heart does not receive much blood to pump into the body. This means that both blood pressure and blood supply to the brain are greatly decreased,[1] while below the heart, in the abdominal region and legs, the blood pressure and supply are much increased. The results of the increased pressure in the lower part of the body are not serious if one possesses normal blood vessels. There may be cramping of the muscles of the leg and sometimes rupturing of some of the small blood vessels in the lower leg. Figure 35 indicates how

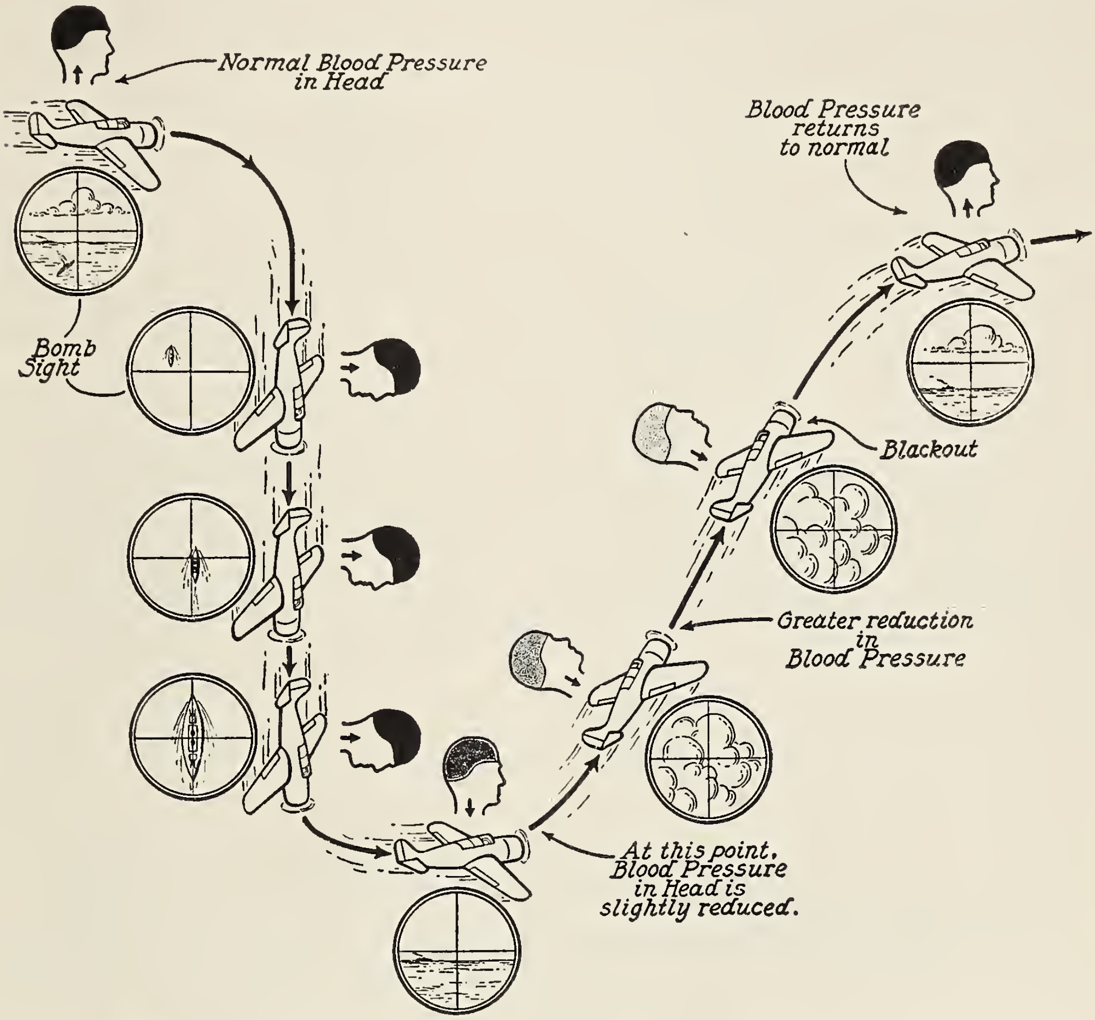

Fig. 35. Sketch showing the lag of the blackout in acceleration

the blackout lags behind the acceleration. This has been shown to be due to the fact that the drop in blood pressure to the head also lags behind the acceleration.

Various methods are used to prevent blacking out. Because the large blood vessels are located along the long axis of the body, the effect of centrifugal force on the flow of blood is

[1] The normal blood pressure in the arteries of the brain is about 120 millimeters of mercury, but it may decrease in a pull-out from 5 to 15 millimeters of mercury.

greatly lessened if one can lie down. As a matter of fact, a man can withstand about 15 gravities when lying on his back and about 11 gravities when lying face downward. In such cases the centrifugal force is acting transversely rather than in a direction parallel to the large blood vessels and does not therefore exert so great a head-to-foot pull upon the blood. In fact, the difficulty met by a person who is lying down is not related so much to effects on the blood stream as it is to pressure on the

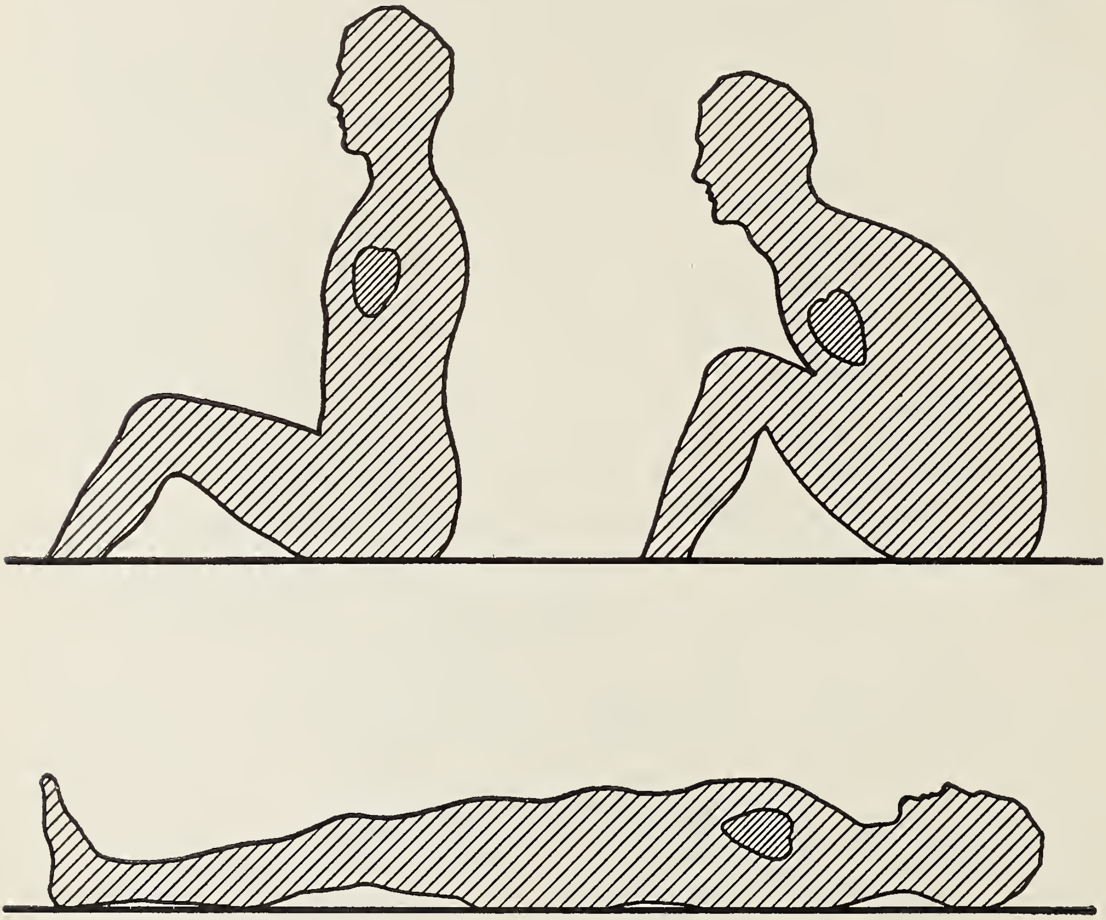

Fig. 36. Possible positions during acceleration

chest, which may become so great as to prevent breathing. If the pilot of a bomber could be placed in a prone position, 5 to 6 gravities would have comparatively little adverse effect on him, but the problem of arranging controls that he could operate in this position is still unsolved. It has been suggested that by means of some mechanical device the seat could be tilted back just before the pilot pulls out of a dive. This is a theoretical possibility, but it presents some engineering difficulties. Even if the mechanical problems could be solved, it has been argued that, in a desperate fight for life, lying on the back would be a physical and psychological handicap. The field of vision would also be decreased in this position.

Test pilots have found that it helps them to tense the muscles of the legs and abdomen; fliers speak of this as "bearing down." Taping of the legs and abdomen has also been tried. Some pilots of bombers yell as loudly as possible when pulling out of a dive. Wearing a broad and tightly buckled belt is of some aid in preventing blacking out. All of these measures are of some value in preventing an abnormal amount of blood from being driven into the lower part of the body, with the consequent lowering of blood pressure in the brain.

Another device that serves to keep blood in the head region is represented by the use of an inflatable belt that may produce as much as 200 millimeters of pressure around the abdomen just as the dive is begun. This belt has been found helpful, but it is uncomfortable and has not proved to be very popular.

The Germans have tried a water suit, which they claim is quite effective in preventing blacking out, but it does not seem to offer a satisfactory solution of the problem. The water suit is worn next to the skin and, as the name suggests, is filled with water. The flier is literally surrounded by liquid, and during accelerations the fluid presses on the body equally in all directions. As a result, the ill effects of acceleration are greatly lessened, because the compression of the body is uniform. It is estimated that a man in one of these water suits could withstand 15 gravities or possibly more.

One of the most practical methods of overcoming the bad effects of high positive accelerations consists of sitting in a position known as the forward crouch (Figure 36). The physical and emotional strain of fighting tends to cause one instinctively to bend forward. It will be seen from Figure 36 that in the crouching position the distance the blood has to be pumped vertically is less than when one sits up straight. Crouching results in a gain in tolerance to acceleration of 3 gravities on a centrifugal force of 9 gravities; in other words, the effect on the body would be equal to that of 6 gravities when one sat upright. Furthermore, the large blood vessels of the upper part of the body (see Figure 34) are tilted so that the acceleration is at an angle to, rather than parallel with, them. The pressure on the abdomen that results from the forward crouch position tends to prevent the pooling of blood in that area. It is also thought that in an air battle such an attitude has a good mental effect on the pilot, which may lead to a secondary effect on the circulatory system, causing increased blood pressure and greater resistance to blacking out.

Negative accelerations. *Negative accelerations* are those that act on the body in the direction of foot to head. They are not of very great practical importance in aviation, but they do occur

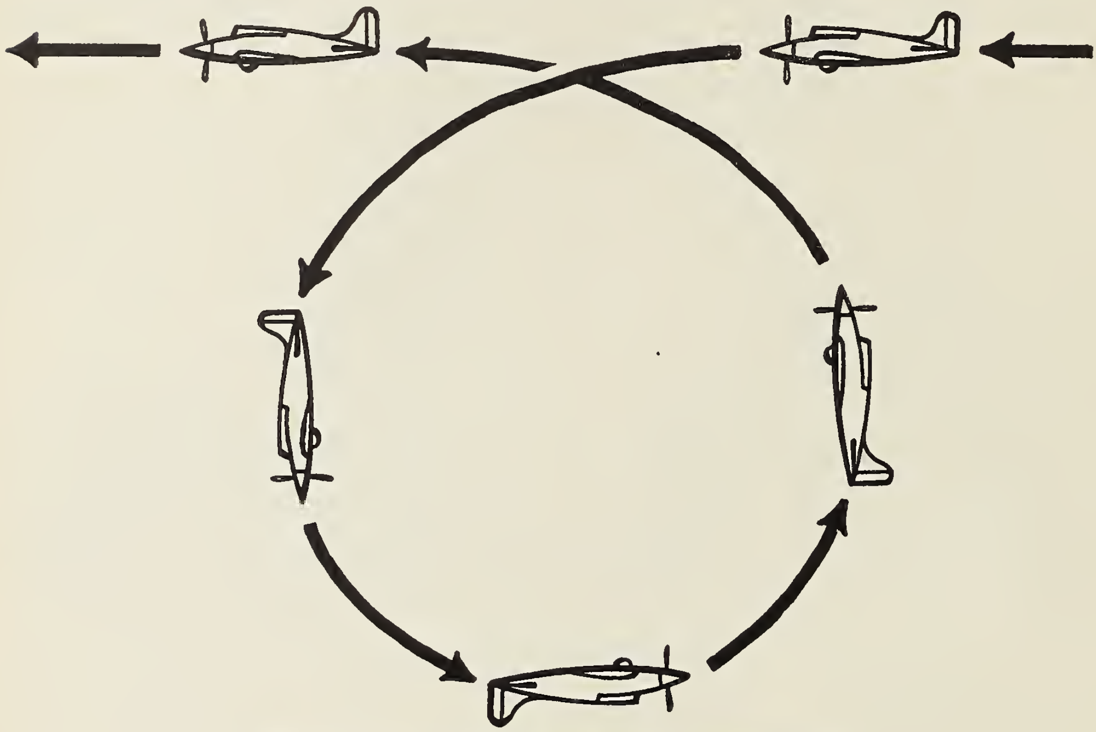

Fig. 37. Airplane making an outside loop

in the course of stunt flying and in a few combat maneuvers. An outside turn or loop (see Figure 37) will produce a high negative acceleration.

The sensation of negative acceleration is that of flying upside down, because the centrifugal force is acting in the direction of head to foot. Hanging by one's feet with the head down gives a good idea of how negative acceleration feels and also, in a minor way, of what the effects on the body may be. The cause of the symptoms in negative acceleration is an increase of blood and blood pressure in the brain. It will be noted that this is just the reverse of what happens in a positive acceleration. Actually the brain and the eyes are more sensitive to an increase of pressure than they are to a decrease.

A negative acceleration of only 2 gravities causes the face to become red, and there is some displacement of the body organs. In negative accelerations of between 3 and 4.5 gravities there is great congestion of blood in the head, and the face becomes intensely red. Pressure in the head becomes so great that it seems as if the skull might burst. The eyes feel as if they were being forced out of their sockets. There is a tendency for the small blood vessels in the whites of the eyes to break, but their breaking is not a serious matter because complete recovery takes place in a few weeks. Sometimes a pilot has the experience of "seeing red," or *redding out,* which is a vision disturbance causing everything to appear red. This probably results from too much blood in the small blood vessels that supply the retinas of the eyes.

At a negative acceleration of 4.5 gravities, which is the highest that has been studied in the case of man, consciousness is not lost, but there is considerable mental confusion, which may last for several hours. Severe headaches are sometimes developed as a result of the high blood pressure in the brain. Sometimes the increased pressure of blood causes large vessels of the brain to break, and death results because of the ensuing bleeding. It is the breaking of a blood vessel of the brain that may cause the serious condition known as apoplexy or "stroke." Negative accelerations of over 2 gravities are usually considered dangerous, because of the possibilities of mental confusion and the rupturing of blood vessels in the brain.

Tolerance of acceleration. In order to develop the greatest possible tolerance to centrifugal forces, it is important not to fly with an empty stomach, especially if one has had a sleepless night. In this condition the normal resistance of the circulatory system is decreased and relatively small forces may lead to a severe blackout. On the other hand, it is not advisable to overeat just before flying. Sleeplessness, alcohol, and excessive smoking greatly increase one's susceptibility to the ill effects of accelerations. A man who attempts flight maneuvers involving high accelerations after a night of carousing is in great danger, because he suffers from a decrease in attention and ability to react quickly; even under normal flying stress he may be in trouble.

Diseases, especially those accompanied by fever, lower tolerance to accelerations. High susceptibility may last for several weeks after recovery from influenza because the circulatory system may return to normal slowly. Great caution should therefore be exercised in flying after one has suffered from a severe fever.

If the results of high altitude and acceleration are combined, they mutually reinforce each other's ill effects. Consequently oxygen should be used in air maneuvers that involve accelerations if there is any possibility that oxygen lack will be developed.

Summary

From the foregoing statements it may be seen that both positive and negative accelerations present definite dangers, but that the former are more likely to be encountered in actual flying experience. The effects are primarily upon the circulation; positive accelerations result in blacking out, and negative accelerations bring about a congestion of blood in the head region. Transverse accelerations, on the other hand, are not likely to produce any ill effects.

Once more it may be observed that individual difference is an important part of the story. Some people are much more tolerant of accelerations than are others. A particular person may also vary in tolerance from day to day, depending on his physical condition at a given time. Ways and means of preventing ill effects have been studied with care, but not much can be done at the present time to prevent them except (1) to avoid maneuvers that produce dangerous accelerations, (2) to change the position of the body so that in effect the accelerations become transverse, and (3) to wear special equipment, such as an inflatable belt.

6

THE SENSE ORGANS AND FLIGHT

THE sense organs, which are concerned with maintaining our balance and keeping us aware of our relation to gravity, are adapted to a life on the earth. When man leaves this normal place of being, these organs are often worse than inadequate for their purpose, for they may give entirely wrong impressions. These false sensations experienced in the air handicap one in learning to fly, especially in learning to fly "blind." Many tragedies of the air have been caused by difficulties for which the organs of balance and orientation are responsible. Therefore it is of great practical value to understand the sense organs and their relation to flight.

Orientation and Balance

The eyes. On the ground, man maintains his balance and orients himself in space by means of sense impressions from his eyes, the vestibular apparatus of the inner ear, and various sensations that originate in the muscles, joints, tendons, viscera, and skin. These are mentioned here in what is thought to be the order of their relative importance. Certainly the eyes are very useful organs of orientation and balance. Trying to stand on one foot blindfolded or to walk in a straight line with the eyes closed will quickly convince one of the accuracy of this statement. We depend on our eyes much more than is generally recognized for maintaining an upright position. Experience has taught us that the body should be parallel to the trees and perpendicular to the ground; so we unconsciously maintain this position in walking or running.

Similarly the eye is the primary sense organ of the flier. Like a hawk, the military pilot must often find his objective from a location high in the air, and he must recognize his enemy quickly. Good eyesight is also important in making emergency landings. In view of the fact that much flying is done at night, it is desirable that the flier be free from night blindness. None-theless, tests have shown that there is a prevalence of this defect among the older pilots. This suggests that it is important for pilots to have a diet high in vitamin A content.

When one is flying in sight of the earth, particularly in maneuvers, the eye is most important for orientation in space, for its acts as a measure of bank, of direction, and of change in direction, and it determines the speed of a turn. In so-called blind flight it is the only organ that can give a correct idea of position in space, because it is able to observe the numerous instruments required for this kind of flying.

The eye, the vestibular apparatus of the ear, and the body muscles are interrelated and correlated through the nervous system to keep the body in the desired position. Studies show that, when the head is rotated, the eyes move in a series of jerks (nystagmus) toward the direction of turn, and that the objects observed appear as separate images rather than as the blurred picture that would be seen if the eyes moved at a uniform rate. It is a series of images that you see as you read this line; the eye does not sweep across the page uniformly but moves by jerks, which are called fixations.

The eyes differ from all the other organs of balance in that they are not affected by linear accelerations, centrifugal forces, or the pull of gravity, as is the balancing mechanism of the ear. While the eyes cannot determine in which direction the earth is moving because of gravitation effects, yet they are not "fooled" by flight accelerations, which may act in any direction.

The semicircular canals in the ears. A man on the ground with his eyes shut determines his movements and his position principally through the balancing organs (the vestibular apparatus) of the ear. Chief among these organs of body balance and orientation are the semicircular canals, which detect movements of rotation.

Three semicircular canals (see Figure 38) occur in each inner ear. It is because each of them forms about two thirds of a circle that they are termed semicircular canals. Two of these canals are vertical and one is horizontal in position. This arrangement, in which each semicircular canal is at right angles to the two others, makes possible the detection of rotary motion in any plane. Such detection depends upon the fact that these canals are filled with a liquid, and that a group of sensory hairs passes through their walls at a certain point known as the ampulla. If the head is turned to the left, the fluid of the horizontal canal

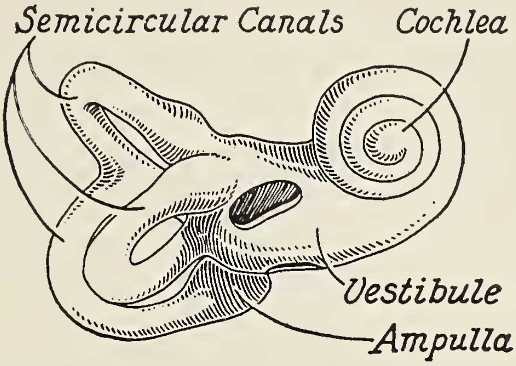

Fig. 38. The semicircular canals of the inner ear

does not move as soon as the canal does, and the sensory hairs are bent to the left (see Figure 39a). This produces a nervous impulse, which is sent to the brain and interprets the extent of movement and direction.

What happens to the semicircular canals of a pilot when his plane goes into a spin as shown in Figure 40? In such a case the

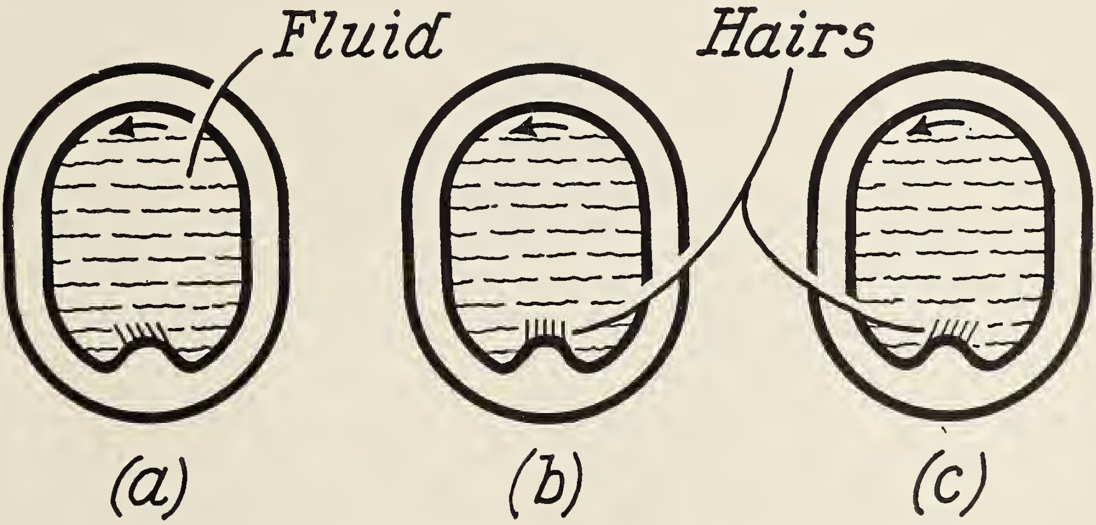

Fig. 39. Diagram to show the action of a semicircular canal

fluid eventually develops the same motion as that of the canal and the sensory hairs again become upright in position (see Figure 39b). When this occurs, the brain receives impulses indicating that the head has stopped turning, which give an entirely false impression to the pilot. Thus it is clear that, if a man shuts his eyes, he has no way of sensing a uniform turning movement after a short time. This possibility of being misled can be well illustrated by twirling a pail of water by the handle.

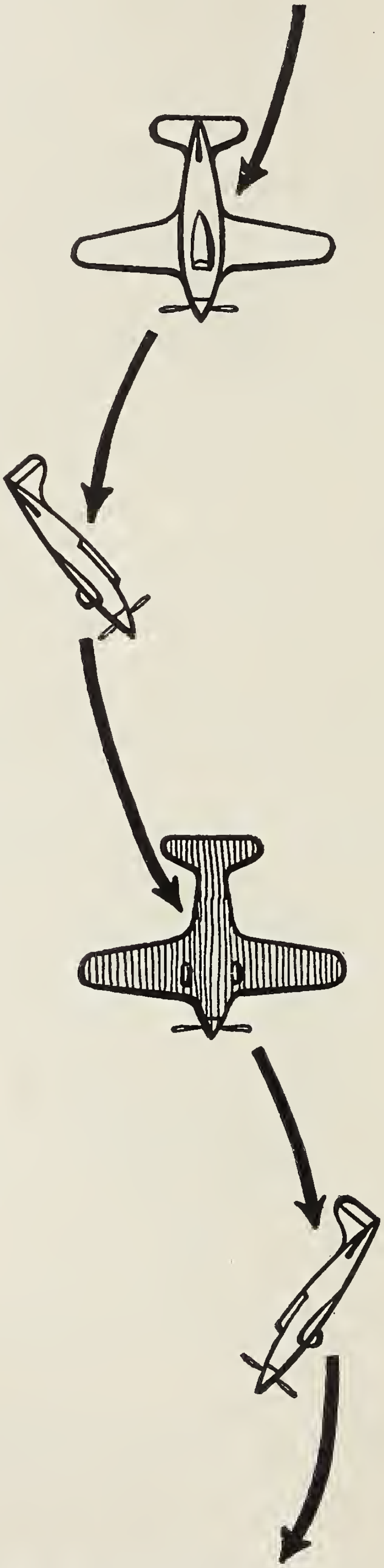

Fig. 40. Airplane in a spin

When the pail is twirled in one direction the water lags behind and exerts a pressure in the opposite direction. Later, however, water and pail spin together. Similarly, the rotary movement of a man's head is suddenly stopped, the semicircular canals will become stationary, but the contained fluid will continue to rotate in the direction in which it was going for a short period of time. This will make the sensory hairs bend in the opposite direction (see Figure 39c), and the brain will receive the false impression that the individual is turning to the right.

At the moment a pilot pulls a plane out of a spin, he has the sensation of turning in a direction opposite to that of the spin. This can be demonstrated by placing someone in a revolving

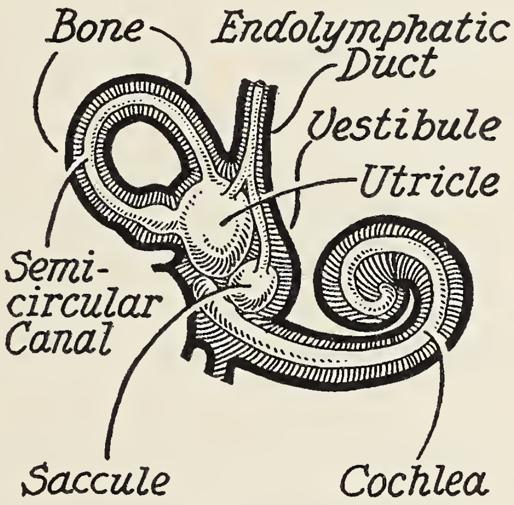

Fig. 41. The inner ear

chair or on a piano stool and spinning him rapidly in one direction, then suddenly stopping the movement (rotation). At the point where the rotary movement of the head is stopped, the semicircular canals become stationary, but the fluid inside continues for a brief interval to rotate in the direction in which it was going. This makes the sensory hairs bend in the opposite direction (see Figure 39c), thus giving the individual the idea that he has begun to turn in the opposite direction. If one is flying blind, this sensation may be very strong; but, if the eyes can be fixed on some point of reference on the horizon, the sensation will be much weakened.

The saccule and utricle. Another balancing organ, not so well known as the semicircular canals, consists of two small sacs located in the inner ear (see Figure 41). These two little sacs are known as the *saccule* and *utricle*. On the bottom of the saccule and utricle there is a membrane of sensory hairs, on which rest many crystals of calcium carbonate, or lime (see Figure 42). This balancing mechanism gives knowledge of linear movements, due to the inertia of the crystals, which causes the sensory hairs to bend. This is interpreted in the brain as movement in some specific direction.

When the head is in an upright position, the sensory hairs are also upright (see Figure 42a). But, if the head is tilted to the right (see Figure 42b), the sensory hairs are bent to the right by the pull of gravity on the crystals. The movement and the direction of the pull of gravity are correctly sensed, so that we can

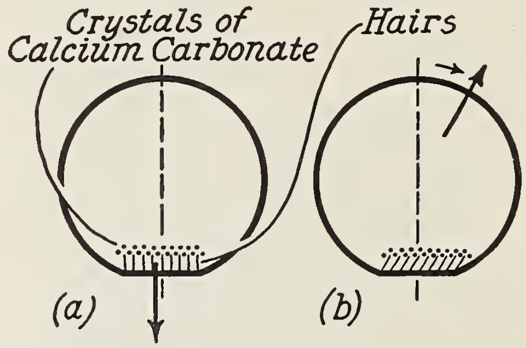

Fig. 42. The mechanism that records linear accelerations, tilt, and pull of gravity

determine which direction is down even with the eyes closed.

But there are situations in the air when one is deceived by this balance mechanism. For example, if a pilot banks his plane vertically in a turn (see Figure 32c), the centrifugal force acts in the direction of the horizon rather than the earth. The direction of the horizon will be falsely sensed as down. This is only one illustration of the many ways in which our organs of equilibrium may give us false impressions.

Other aids to orientation and balance. As previously indicated, sensations from the muscles, joints, tendons, viscera, and skin also help to orient us in space. The muscles, tendons, and joints give information regarding the position of the limbs in relation to the body and to one another. Through the sensory nerves of the skin we are able to feel our position in relation to other objects, such as buildings, trees, and the ground. All these sense systems also perceive the pull of gravity, and through the inertia of the body detect acceleration such as that we commonly experience if a train suddenly starts or stops while we are standing. In each case, because of an automatic control of the nervous system, our muscles contract in an effort to regain the original position. We also sense whether we are moving up or down rapidly when either standing or sitting by the increased or decreased pressure on the body. This fact is well illustrated by the experience of riding over a rough road in a car.

Blind flight. With this background of knowledge concerning the organs of orientation in space, it is now possible to consider some of the special problems connected with flight that torment the pilot, especially when the visibility is zero. It is frequently said that a good pilot "flies by his pants"; but, regardless of how good a pilot's sense of balance may be, he cannot be trusted to fly blind. By *blind flying* is meant flying without sight of the earth or anything else that would serve as an aid in recognizing position. Such flying may be made necessary by the presence of clouds, fog, dust, darkness, or other causes.

Without vision, one lacks the ability to walk in a straight line but tends instead to move in a circle to either the left or the right. Even birds cannot fly blind, as has been shown experimentally by releasing them blindfolded from an airplane; they make no effort to fly but glide directly to the earth. This is to be expected, for the balancing mechanism of the inner ear of a bird is similar to that of man; therefore neither man nor bird is equipped to fly "blind." Man, however, has solved the problem through the invention of instruments which give him a reference object that he can see and in relation to which he can determine the pull of gravity. Thus he has developed the technique of instrument flying. One of the flier's greatest problems in flying blind is to depend on his instruments and to ignore the false sensations that he receives from his organs of balance. Let us now consider some of these false sensations in greater detail.

Imperceptible motion. One reason for failure of the semicircular canals to inform us accurately about our position in blind flying has been learned from experimentation. If a blindfolded person is turned in a revolving chair with an acceleration of less than about 2 degrees per second, the motion is not felt. If a blindfolded person in a revolving chair is turned at an acceleration of less than 2 degrees per second and if the rate of revolution is then gradually increased until it becomes quite rapid, the individual is not aware of any change at all. Also the average person can be tilted about 24 degrees upward or 10.6 degrees downward without sensing any change. The implications for aviation are quite obvious, for the dropping of a wing, a climb resulting in a stall, or a transition developing into a dive might occur without the pilot's being aware of any of them insofar as his ears are concerned.

Underestimating the amount of bank. If, when the plane is going into a turn, the rate and amount of bank is below what is sensed by the organs of equilibrium, the degree of bank is likely to be underestimated in blind flying. Consequently the aviator banks too sharply in making the turn and may bank in the opposite direction when he attempts to level up his plane.

Unawareness of bank. One is usually aware of any sideways movement, because the pull of gravity on the body makes us sense this tilt. However, in an airplane such a tilting may not be sensed, because the body is acted on by both gravity and centrifugal force, and the human mechanism for equilibrium cannot distinguish between these two forces. They are fused into a common effect, and direction in relation to the earth's surface cannot be determined if the horizon is not in sight.

Sensation of tilt to the opposite side in a skid. If the airplane skids during a turn because it has not been given adequate bank, the centrifugal force on the body does not act in a direction perpendicular to the transverse axis of the plane. The result in blind flying is a feeling that the plane is banked in the opposite direction from its real position.

False sense of climbing while turning. If a relatively sharp horizontal turn is made, the banking of the plane may not be felt, but there is an awareness of being pressed firmly into the seat because of centrifugal force acting in the direction of head to foot. This sensation may be misinterpreted and thought to be that of a sharp upward climb (in which the pilot is always pressed harder against the seat). The natural reaction is to push forward on the stick to level up the plane, which in this case will cause it to go into a dive.

False sense of diving in recovering from a turn. When recovering from a turn, the pressure of the body on the seat is decreased. This gives a sensation similar to that when the plane is nosed down from level flight into a dive. Thus, in blind flying, return to level flight creates a feeling of diving, which may cause the pilot to pull back on the stick. This may bring about a steep climb ending in a dangerous stall.

Optical illusion from flying between two layers of clouds. If no horizon is visible when one is flying between two layers of clouds that are not exactly horizontal, there is the temptation to use the clouds as the horizon, so that the airplane is flown at a tilt corresponding to the slope of the cloud layers (see Figure 43). The illusion regarding the horizon can be so strong that the flier may doubt the accuracy of his indicator. This illustrates how important a part the eyes play in giving the pilot a sense of position under certain circumstances, also that one may be tricked by the eye as well as the ear.

False sensation of rotation. Our discussion of the effects in the semicircular canals of rotary motion would suggest that in blind flight our ears may hinder more than help in some situations. For example, if any rotary motion persists for a short time and is then stopped, the fluid in the affected canals continues to rotate, thus creating the feeling of rotation in the opposite direction (see Figure 39c). This may have serious consequences for the pilot, who, after recovering from a spin to the right, has the sensation of turning to the left. When he tries to correct this seeming left turn, he causes the plane to go into a right spin.

Sensation that the airplane is tipping beyond the vertical. In a very sharp curve, if the head is suddenly turned downward to read a low-placed instrument, the vestibular apparatus of the ear is acted upon by two different rotary motions at the same time. The net result of this is a feeling of diving, and the false impression may be so strong that one believes the airplane had even nosed down beyond the vertical. Apart from individual differences, the strength of this sensation is directly proportional to the speed at which the turn is made and the rapidity of the head movement.

In a spin at very high speed the feeling of tipping downward may occur even though the ground is in sight. If the pilot believes that he has gone over the vertical, he naturally responds by pulling the stick back in an attempt to nose the plane up. This only leads to a prolongation of the spin.

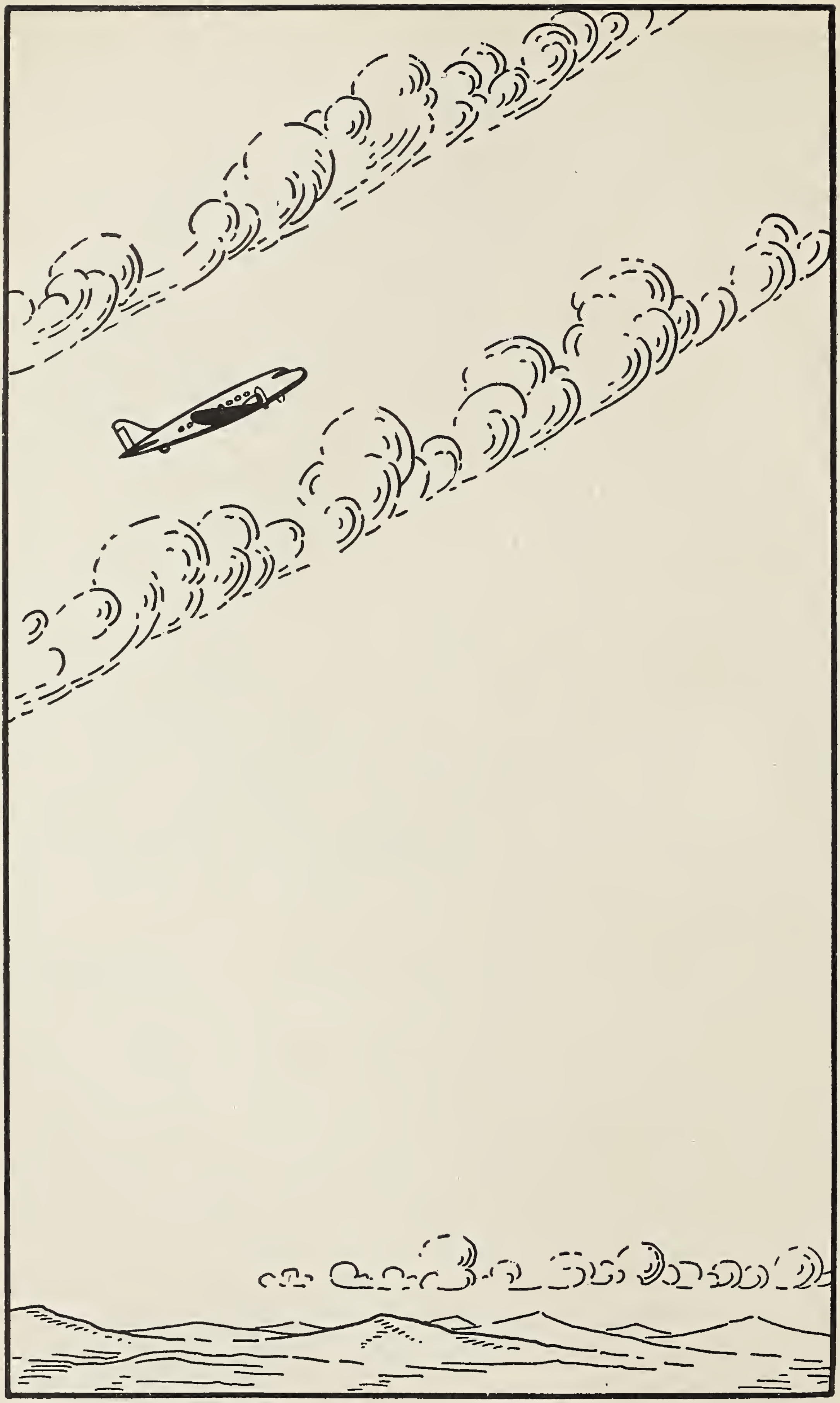

Fig. 43. An airplane being flown at a tilt corresponding to the slope of the clouds

Because of these facts, it is advisable in a sharp turn or spin to hold the head still.

Sensation of opposite tilt. In blind flight, if the airplane suddenly rolls sharply to the right and then recovers very slowly, the vestibular apparatus will record the tilt of the body to the right but not its recovery to the upright position. As a result, the pilot feels distinctly that he and the plane are tilted to the right. Even if he has blind-flying instruments that show the plane to be back in a vertical position, this illusion is so strong that he may still feel that the right wing is down. In an effort to overcome this false feeling, which is quite disturbing, the pilot leans over in his seat to the left, to what seems to be an upright position. Of course he is actually leaning to the left;

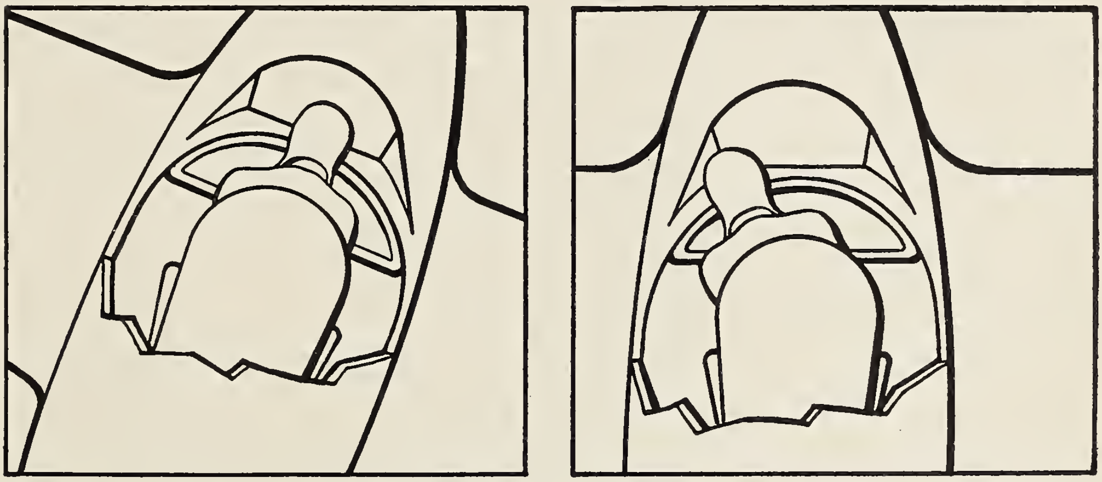

Fig. 44. The left sketch shows that the pilot "feels" as though the plane is tilted to the right. The right sketch shows the actual position of the plane and the pilot leaning to the left, which he senses to be the vertical.

but, if he feels better satisfied about his own position in space and continues to guide his plane by instruments, all will be well (see Figure 44).

Instrument flying. Considering all the possible sensations that may develop during blind flying—and we have given only a partial list—it is not difficult to understand why instrument flying has become so important. The flier who is out of sight of the earth or horizon is likely to lose accurate knowledge of his position in space very quickly. Pilots without blind-flight instruments sometimes come out of the clouds upside down, and it is not until they see the earth that they are aware of being in an abnormal position. The fact that the sensory illusions sometimes are so strong that the pilot begins to doubt his instruments suggests the chief difficulty in learning instrument flying. In fact, most of the time spent in learning this skill is devoted to nothing more or less than learning the rule, "The sense organs may deceive, but the instruments tell the truth."

This principle may be more easily accepted by the inexperienced student pilot than by a veteran of the air, who has a well-developed "flying sense." The latter feels himself to be part of the airplane; he considers the ship an extension of his own sense organs to such an extent that he may fly without watching any instruments. Before instrument flying a "flying sense" was believed essential to success. It is still very useful in making landings and in acrobatics, but instruments are playing an increasingly important part in aviation.

In conclusion, it should be emphasized that all of the deceptive sensations of blind flight described here may be experienced in ordinary flying. In general, however, if air maneuvers are carried out slowly, false sensations are less likely to develop. Rapid and involved maneuvers may cause dizziness, nausea, and vomiting even if one is not flying blind.

Airsickness

Another phenomenon that has to do with the sense organs is airsickness. This condition is a real problem in aviation. The development of large airplanes for military and passenger service has given rise to the need for large crews. As will be pointed out later, any member of the crew is more likely to be airsick than the pilot. This is a serious matter in the case of military crews, who may become almost helpless in rough air. Airsickness in commercial passenger transportation also is of considerable importance, for air passengers are a largely unselected group and are therefore more susceptible to the condition than are regular aviation personnel. It is not merely a matter of distress and embarrassment during flight for the airline passenger to become ill, but it may also involve partial or total inability to carry on work for hours or days afterward.

For many travelers the possibility of airsickness no doubt may be the deciding factor in choosing to go by train, although some become car sick. In this connection it is interesting to consider the probable influence of airsickness and seasickness on the competition between airlines and ocean liners. On the face of the matter it would appear that airplanes have an advantage, because they are likely to find smoother going than are water-borne craft, and at worst the passenger will be subjected to discomfort for a much shorter time in the air than on the water.

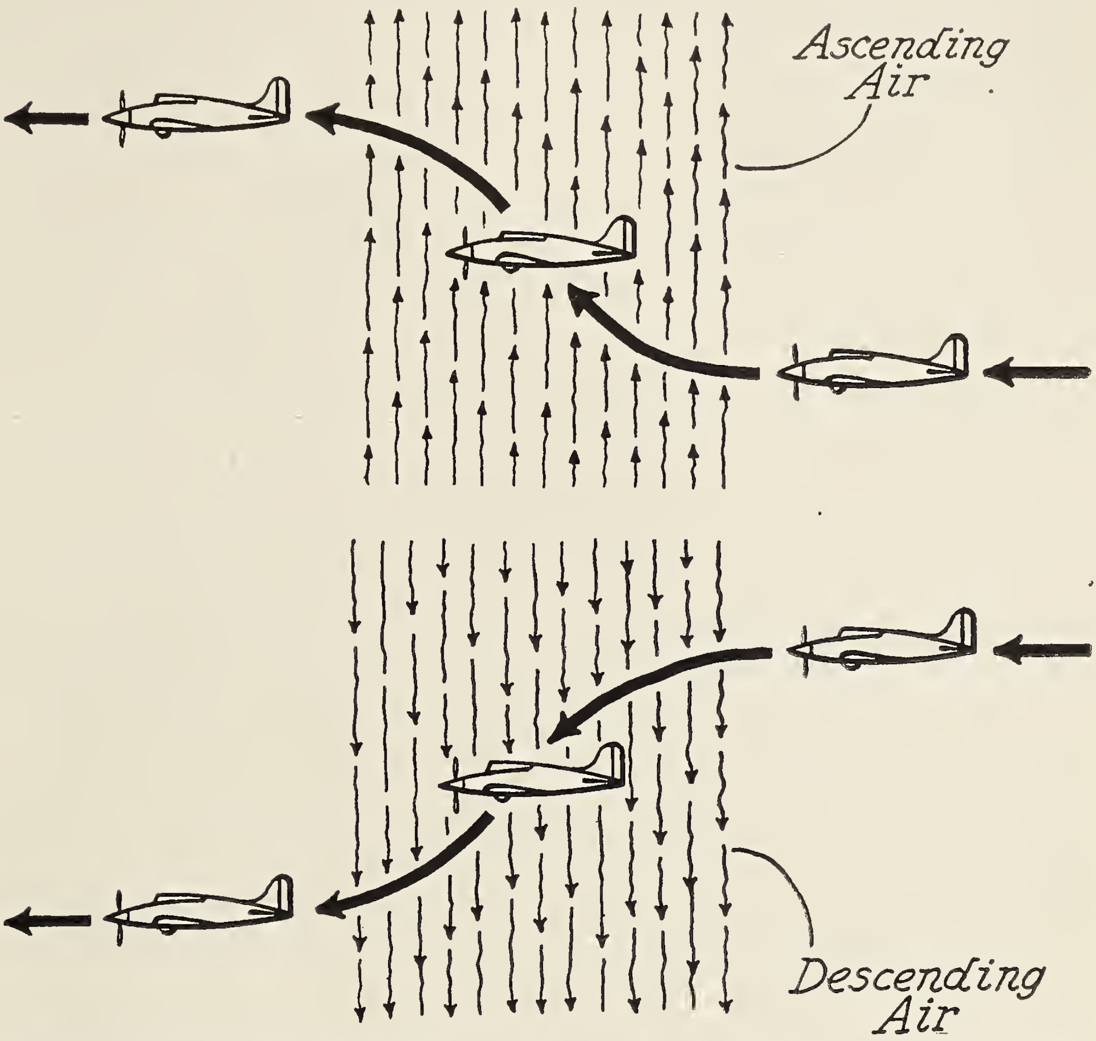

Fig. 45. Airplane affected by (top) strong ascending currents of air and (bottom) strong descending currents of air

Causes of airsickness. In the early history of aviation the term *airsickness* was applied to almost all kinds of illnesses suffered by the flier. However, it is now defined as a condition due largely to rotary motions and vertical accelerations in aircraft flight and has no reference to altitude sickness or oxygen lack.

Airsickness develops essentially as does seasickness, because of up and down movements, especially those that are combined with a rolling from side to side. In an airplane that is strongly ascending (see Figure 45) or descending, air currents cause up and down movements of the plane. People often say that the air is "bumpy." Squalls also may cause an airplane to pitch from side to side.

Airsickness, like its twin seasickness, is not very well understood; yet it is known that, if the vestibular appartus is destroyed, a person does not become airsick. Furthermore, the severity of the condition is in proportion to the amount and duration of motions in the air that disturb the vestibular apparatus. These facts suggest that airsickness is entirely an internal ear problem. It seems probable, however, that other sensory organs contribute to the condition. In fact, there is evidence that airsickness occurs only when there are conflicting impressions from two or more organs of orientation. Actually, then, a combination of factors seems to be the cause, most of which have not been well identified up to the present time.

Conditions under which airsickness develops. Development of airsickness is hastened by the presence of bad air in poorly ventilated cabins and by physical factors, such as the feeling of insecurity often experienced by those making their first trip.

In military aviation the snap roll—a violent 360-degree rotation of the airplane about a horizontal axis while in level flight—is the maneuver that most often causes airsickness (see Figure 46). The Immelmann turn is a close second.

Tendency (susceptibility) to airsickness. The tendency to airsickness differs greatly among individuals. Most people adapt themselves quickly to the motion of an airplane. The problem is somewhat easier for the pilot than it is for others, because the former sits close to the center of rotation and is actively flying, not sitting passively like the passengers. Nevertheless, few people leave an airplane after a long flight in rough air with a complete feeling of well-being. This is especially true if they sit near the tail of the plane, for the movement greatly increases with distance from the cockpit.

One who becomes train sick, seasick, or swing sick probably has a sensitive vestibular apparatus and is therefore likely to suffer airsickness. When being examined for military air service, the candidate is asked if he has ever been swing sick, train sick, or seasick. If the answer is yes, the applicant is given the Baranay chair test. This consists of placing the candidate in a revolving chair and turning him from left to right and right to left a given number of turns in a given number of seconds. The test is made both with the eyes open and with the eyes closed. It usually is not disagreeable, but most of those tested experience some dizziness.

Some persons claim that they are never airsick, but it seems to be a rule rather than an exception for passengers and stu-

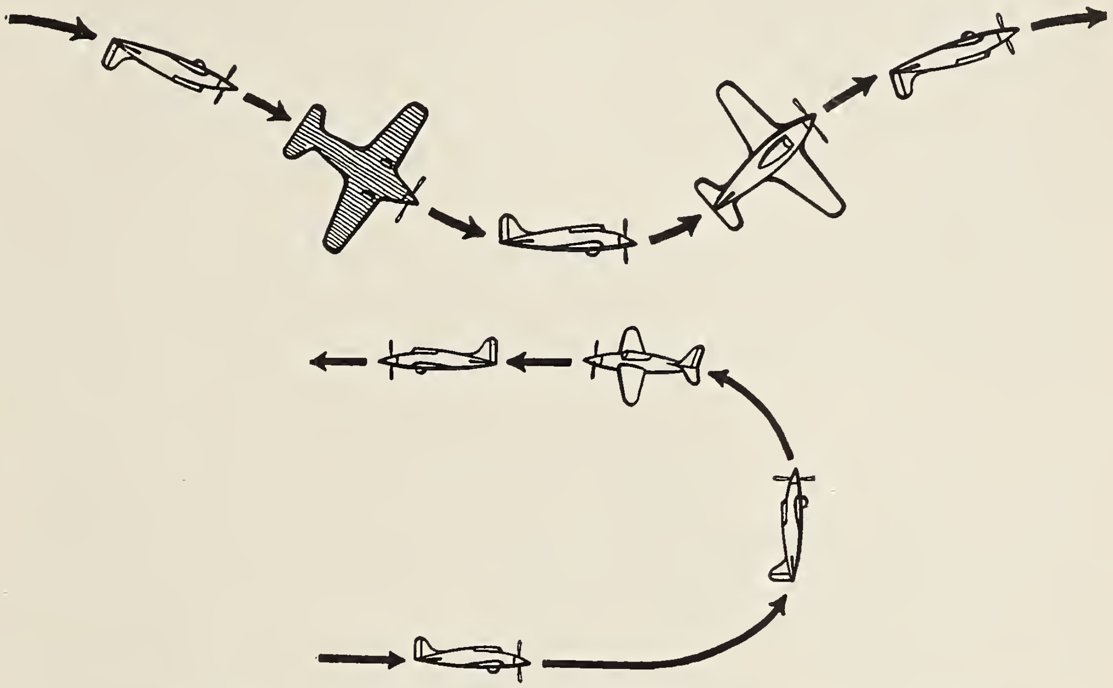

Fig. 46. The snap roll (top) and the Immelmann turn (bottom)

dent pilots who fly infrequently to be airsick. As a matter of fact, a recent study of student aviation showed that almost 100 per cent suffered some degree of airsickness. Most of those who are airsick during their first few flights become less susceptible to airsickness with experience; on the other hand, some actually become worse.

Symptoms. The first symptoms of airsickness are almost always felt in the digestive tract, which means that the disturbance originating in the sense organs has spread through the nerves to other parts of the body. There usually is a slight nausea, which gradually becomes worse and frequently leads to vomiting. It may require several hours for an attack of airsickness to reach the vomiting stage, but in some cases violent vomiting starts within a few seconds, especially during certain types of aerial acrobatics. The face also develops an anxious expression, and it becomes pale because of the contraction of blood vessels. When vomiting is severe, the face becomes yellowish or greenish gray in color, and the victim appears to be very ill. A sweat causes the skin to feel cold and clammy, and there is a general sensation of being "sick all over." This may be accompanied by a feeling of unreality, and earlier apprehensiveness may change to an attitude of "I don't care."

The foregoing description of airsickness is that of a relatively severe attack. However, symptoms vary from slight fatigue, annoyance because of tobacco smoke, moderate headache, distaste for activity, and slight nausea to violent vomiting with great depression of mental activity and finally complete physical prostration.

Prevention of airsickness. In general, a mind that is free from worry and fear helps to prevent airsickness. Avoidance of bad odors, such as the smell of oil, or stuffy air tends to forestall trouble. When the air is rough some people find that fixing their eyes on definite objects on the ground is of considerable benefit. Others discover that concentration on reading, writing, or some activity requiring manual skill prevents the development of symptoms. Such activities of course tend to keep the mind off the motion of the airplane.

Any indigestion experienced just before flight is likely to hasten the development of airsickness. This is especially true if one has drunk too much liquor or has overeaten just before taking off. On the other hand, an empty stomach may be the cause; most people find that a light meal an hour or two before flight does not cause any trouble. Those who are prone to become airsick should attempt to sit near the cockpit, for less movement is experienced in this position than anywhere else.

Treatment of airsickness. There is no specific medicine for the cure of airsickness. This partly accounts for the fact that so many different remedies are commonly suggested. Most of the drugs used in attempts to relieve the condition are of a soothing (sedative) nature. Their effects are likely to be quite variable. Actually those that are most useful insofar as airsickness is concerned produce other undesirable results and therefore are not preferably recommended.

A person suffering from airsickness should fix his gaze on the horizon if possible. The airplane in which he is riding should be well ventilated at all times. Passenger transports often have a ventilating system that makes it possible to direct a stream of cold air on the face of the passenger, and some people find this helpful. Most individuals are made worse by the sight or odor of food, although some tolerate a little carefully selected food. Only small amounts of liquids should be drunk. Some people obtain relief by lying down. This position prevents the stomach from bouncing up and down in bumpy air.

Finally, it is comforting to know that, regardless of how airsick one may be, there are no records that anyone died from this condition. One always gets well even without any medical treatment, and the most serious effect is only temporary disability. Furthermore, people who once overcome airsickness are not likely to experience it again. Seasoned air travelers, like sailors, therefore are usually immune. Resistance to airsickness can usually be acquired by repeated flying in rough weather.

Flight Fatigue

Aviation calls for a high degree of physical efficiency. A pilot should be at his best at all times. His job demands alertness, keen judgment, quick reactions, and good co-ordination. A glance at the instrument panel of a modern transport airliner (see Figure 47) or a military airplane will convince one that flying makes great demands on the nervous system. The high speeds of an airplane make it necessary to give constant thought to the job of navigation. Some air accidents in which planes have crashed into mountainsides have doubtless resulted from brief inattention. Hence it can be seen that anything that decreases the flier's efficiency is of first importance.

Fatigue. Fatigue is a serious problem in aviation because it results in a general lowering of efficiency, thus affecting many of the abilities of an otherwise good pilot. This is strikingly illustrated by the fact that between 50 per cent and 70 per cent of air accidents are estimated to be primarily due to fatigue.

Causes of fatigue. Everyone thinks he knows the meaning of fatigue because it is a common biological experience. Yet it is not easy to define this term, because it has to do with effects upon the muscles, the nervous system, and other parts of the body. For the purpose of this discussion, however, we can say that flight fatigue is a condition produced by mental and emotional strains which lower ability to do good work. It is accompanied by such sensations as tiredness, mental dullness, sleeplessness, and nervous irritability. The flier does not use any great amount of muscular energy; but he must concentrate on

Fig. 47. Instrument panel of a commercial transport airplane

his work all the time, and he is subjected to various emotional stresses.

Types of fatigue. People often speak of physical (muscular) fatigue and mental or nervous fatigue as if they were two very different things. Actually they are combined to produce the symptoms that we all know so well. Hard physical work may produce a tired mind, and it is just as true that great mental effort may cause physical or muscular weariness. This has been demonstrated by means of a special device that electrically stimulates a muscle of the finger to contract. Stimulation of a given strength caused the muscle to contract fifty-three times before it became exhausted. But, when an oral examination was given for three and a half hours before the muscular test was made, it was found that the same stimulation caused only twelve contractions before muscular exhaustion developed. Such a result indicates that physical fatigue and mental fatigue are not entirely distinct; nevertheless, it is convenient to speak of fatigue produced chiefly by muscular effort as physical and that caused principally by nervous stresses and strains as mental.

Fatigue may also be classified as temporary or chronic. Temporary fatigue is a type of weariness that is relieved by a good night's sleep. On the other hand, chronic fatigue is not relieved by rest but persists and may become more and more prominent.

Physical conditions and fatigue. Some airplanes have small cockpits, which force the pilot to sit in one position all the time. Cramped in this confined space, various parts of the body soon become uncomfortable and muscles begin to ache. Wind due to rapid movement of the ship through the air is irritating and causes fatigue when a cockpit is open. Unless there is an automatic pilot, the hands and feet must be kept constantly on the controls; this may be very tiring if the flight is long. Fatigue is greatly reduced in the case of larger airplanes, which provide more cockpit space and have automatic pilots.

Noise and fatigue. Many studies have shown that noise produces fatigue. Studies of the effect of noise on workers have shown that their efficiency may be reduced 10 per cent to 20 per cent according to the intensity of the sound, its nature, and the kind of work being done. A steady continuous noise is much less fatiguing than an irregular one; a low-pitched noise is less damaging than one that is high in pitch.

The noise in an airplane comes chiefly from the motor, vibration of the fuselage, and sound produced by the slip stream. In addition, the modern pilot is exposed to sounds from the headphones of the radio. It is known that repeated and long exposures to noise may produce deafness, and there is some evidence that fliers have actually suffered loss of hearing from such causes. With the soundproofing of commercial and military airplanes, however, deafness among pilots should rapidly decrease. Even without soundproofing, the ears can be given a good deal of protection by wearing ordinary cotton plugs in them.

Noise is not much of a problem in the case of airline passengers. The cabins of modern transport airplanes are so built that outside sounds are at least toned down. They may remain a source of discomfort and irritation, but they are not damaging to the organs of hearing.

Glare. Glare may produce fatigue. Flying into the sun, over snow, clouds, desert, or water on a sunshiny day commonly causes fatigue from glare. Reflection of light from the polished surfaces of an airplane also cause such fatigue. Daylight glare can be rendered harmless by the use of good tinted goggles or sunglasses.

At night, glare may be caused by too bright cockpit lights, flames from exhaust stacks, beacons, signal lights, floodlights, and searchlights. Glare at night creates a fatigue problem that is more difficult to meet. The use of tinted glasses is unsatisfactory in this case, for it makes reading of the instruments and observation of outside objects difficult if not impossible.

Vibration. Most people are surprised in their first air travels to find so much vibration in transport airplanes. It is even more pronounced in military airplanes and may be responsible for considerable fatigue. Vibration is more noticeable when one is standing or sitting with the body tense than when one is lying down relaxed. Cushions between the body and the vibrating structure of the airplane provide some protection.

Oxygen lack. One of the most important causes of fatigue in flying at great heights is oxygen lack. The degree of fatigue experienced is in proportion to both the amount of oxygen lack and the length of exposure. If oxygen is not used at high altitudes, fliers become excessively tired and prolonged aftereffects sometimes result.

High altitude. Apart from oxygen lack, high altitude in itself brings on one type of fatigue. Its real cause is not definitely understood. Some authorities think that it results from the effects of lowered pressure on the body. There also is evidence that this type of fatigue may be due to aeroembolism, for it develops at about the same height that nitrogen bubbles appear in the blood. Furthermore, some people can avoid it by inhaling 100 per cent oxygen for about a half hour before ascent, thereby driving a good deal of nitrogen from the body.[1] Whatever the causes may be, high altitude fatigue is rarely felt during flight but usually develops from one to three hours after flight.

Cold. Cold produces fatigue by increasing the use of energy by the body. Metabolism is speeded up, and some energy is even expended in shivering. At the same time the body's use of oxygen is lowered. The result is a fatigue effect that is similar to the effect of oxygen lack at high altitudes.

Emotional factors. There is serious question as to whether there is any other vocation in which emotional factors play as important a part as they do in aviation. Man is out of his element in the air, and there are dangers peculiar to this new environment which produce emotional stress. The pilot may have responsibility for an airplane costing about $200,000, to say nothing about the lives of passengers. The necessity for constant alertness is always tiring; and, when there is added to this the awareness of possible penalty for even a moment's relaxation, the mental stress is great.

The more dangerous the flying experience, as in a bad storm or in actual aerial combat, the greater the nervous strain and the sooner the flier becomes exhausted. Nervous fatigue usually is completely relieved by proper rest; but, if the pilot is overworked, nervous disorders may develop.

General consideration. At the present time conditions under which fliers work are such that they do not suffer undue fatigue. The situation is likely to be somewhat different, however, when war duties make special demands upon military aviators.

There are several reasons why working conditions have been improved in recent years. These include better knowledge of weather conditions, more comfortable and safer airplanes that are easier to handle, better landing facilities, reduction of noise and vibration, improved protective devices, the presence of copilots, fewer flying hours, more interest in health conditions, and better and more frequent checks on fliers, planes, and equipment in general.

It is also well to remember that the amount of stress and

[1] A technique that is also used in avoiding aeroembolism (see page 70).

strain experienced by one aviator may affect him seriously, while another flier may not become unduly fatigued under the same conditions. Thus we again encounter the principle of individual differences, which plays an important part in the biology of flight.

Summary

In this chapter the story of the sense organs in relation to flight experiences has been reviewed. The most important of these organs are clearly the eyes and the ears, but the sense of touch has a good deal to do with maintaining balance and orientation. One fact that emerges from the discussion is that the senses are often "tricked" in flight experiences, a fact that is particularly true when the pilot is flying "blind." This is one reason why instrument flying has become so important in recent years.

We have also noted that, while ordinary airsickness cannot be fully explained, it is clearly due to a confusion of many sensations that originate in the sense organs. Some people are more susceptible to airsickness than are others, and a few are probably never able to overcome the handicap. We should remember that airsickness may be developed at any level of flight; it is not one of the conditions that appear only at high altitude.

The causes of flight fatigue and its dangers have also been outlined. Undoubtedly it was more of a menace in the early days of aviation than is now the case. In recent years many improvements of aircraft, methods of handling air traffic, and other innovations too numerous to mention have added greatly to the comfort and security of fliers. The various causes of flight fatigue, however, cannot be removed entirely. We shall always have to reckon with this factor.

7

PHYSICAL FITNESS FOR FLIGHT

IN THE preceding chapters you have encountered one great biological truth again and again. It is the fact that no two human individuals are exactly alike.[1] Some are well fitted for particular kinds of work, and others excel in different fields of endeavor. In selecting good pilots or other personnel for air crews, this principle must be recognized. It was largely ignored by some nations in the early days of military aviation, and the results were disastrous.

Despite what has just been stated, one natural, but erroneous conclusion must not be formed. We have seen that some people have unusually good ability to resist airsickness, altitude sickness, aeroembolism, the effects of low temperature, and the results of acceleration. We might decide that only people with such powers make good fliers. This would be a mistake. In the first place, the disorders mentioned (except airsickness) are not likely to be encountered in ordinary, low altitude flight. Moreover, we have seen that some of the hazards can be avoided if proper equipment is provided. In addition, there are other qualities that are just as important and perhaps more so in some cases.

What we must not fail to note is that great differences exist even within a group of people who are recognized as good airmen. Some of them, for instance, may be noted for their ability to withstand oxygen lack. Others will prove superior in withstanding blackouts. Still others may be marked by their relative indifference to cold. The rest are outstanding for other good reasons.

[1] It is true that identical twins are amazingly similar; nevertheless, small differences exist even in such pairs of individuals.

Another popular error is to conclude that obviously strong and vigorous people make the best pilots. The fact is that some do and some do not. John Doe may boot a football sixty yards or run the hundred-yard dash in ten seconds, and he may also prove to be very good pilot material. On the other hand, he may be a failure as an aviator. John may find himself a

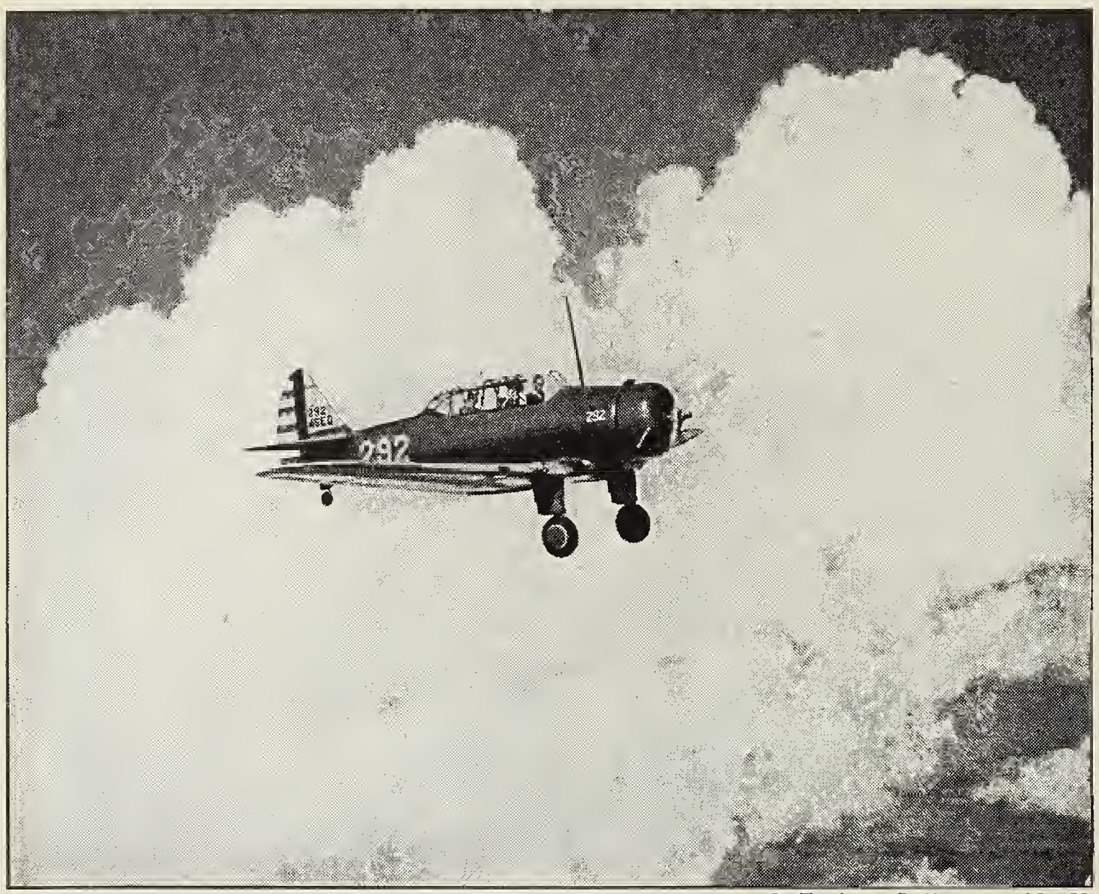

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Fig. 48. A trainer airplane. Trainer planes are flown with comparative ease.

chronic victim of airsickness and lacking in necessary powers of vision, as well as in various other qualities. Or he may prove to be a good crew member for certain purposes, but not a particularly acceptable pilot.

The chances are, however, that the average normal person can make a good showing in the majority of cases. This does not mean that he will become a "super pilot," but that he will learn to fly safely and with about as much ease as he would learn to operate an automobile. If we required the level of skill in all car drivers that is demanded of pilots, there would be far fewer cars on our highways.

But there are some people who clearly should not be encouraged to fly, except perhaps as passengers. In an effort to weed them out, various tests of physical fitness have been designed by the Civil Aeronautics Administration and by the Army and Navy air services. Some of the specific items in these tests are beyond the scope of this book, but other provisions will be discussed in the following pages.

The Nervous System and the Sense Organs

Candidate's medical history. A sound nervous system is a first need of an aviator, just as it is in the case of an automobile driver or in thousands and thousands of other people who do many kinds of work. A good deal can usually be learned about the state of this system from study of the medical history and personal habits of an individual. For example, if he is known to be a victim of epilepsy, the possibility that he may have a seizure while piloting an airplane must be recognized. Such a person would normally be barred from flight. Similarly a person given to fainting spells or one who had suffered severe head injuries in the past would be open to grave suspicion.[2] Any record of amnesia (loss of memory) would be a reasonable cause for disqualification.

The medical history might also indicate a good deal about the mental state of an individual. Some people are known to have abnormal fears of certain objects or experiences. Others worry far more than the average person does and often about trivial matters. Some are known to be highly nervous at all times or to become angry or excited for no good reason. Such facts and others related to them suggest that the candidate for pilot would not be satisfactory.

Drugs, alcohol, and tobacco. Drugs, alcohol, and tobacco have effects on the nervous system. The use of narcotic drugs of course renders an individual quite unfit for aviation purposes. Even those who habitually depend upon various medicines (whether they need them or not) are commonly rejected by the military services. Alcohol, which acts upon the human body as a depressant, slows down reaction time[3] to a marked

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[2] It might of course be shown that fainting had only accompanied severe pain, and that head injuries had left no permanent effects. In such cases a candidate would normally be judged acceptable.

[3] That is, the time between the stimulus and the response. The reaction time varies greatly among different people and in the same person at different times.

degree. Those who use alcohol to excess are ordinarily disqualified. The tobacco habit is also likely to have greater or lesser adverse affects upon the nervous system, depending upon the individual and the amount of tobacco he uses. Steady smokers are usually examined with great care to determine whether they have suffered any serious injury as a result of smoking.

The sense organs. The sense organs, through which we experience sight, hearing, smell, taste, and touch, enable us to know where we are and what is going on about us. The sense organs are really the outposts of the nervous system; they receive all sorts of stimuli. Needless to say, they must be reasonably efficient in the case of an aviator, because he depends on them in performing almost every task that he must do. Chief among the important senses is sight, which we shall consider first in this discussion.

Acuity of vision. Sharpness of vision is called *acuity.* In Chapter 1 we learned that some of the birds (hawks, for example) seem to possess acuity of vision to a degree that we cannot hope to rival. The pilot of an airplane, however, must have reasonably sharp eyesight, because he must see landing fields clearly, be able to observe which way the wind sock is being blown, and read the names of towns that are painted on the roofs of buildings. In military work he must often be able to check the location of many different things down on the ground against a map, as, for example, when he is seeking a given bomb target.

Acuity is tested by the use of an eye chart, or reading chart. This is the familiar examination in which the subject sits twenty feet away from a chart and attempts to read successively smaller lines of numbers.[4] Each eye is tested separately and retested with glasses if the subject uses such a means to correct his vision. What is known as 20/20, or the ability to read a certain line[5] accurately, is considered to be 100 per cent vision. It is required that candidates for certain military classifications possess 20/20 vision in both eyes without resorting to the use of glasses. Aviators in other classifications and commercial pilots do not have to meet so high a standard, al-

[4] Some charts used in testing acuity bear letters instead of numbers.
[5] The seventh line on some charts.

though commercial pilots must exhibit 20/20 vision in each eye either with or without glasses.

Accommodation. The human eye is focused (see Figure 49) by changing the shape of its lens. This adjustment is called

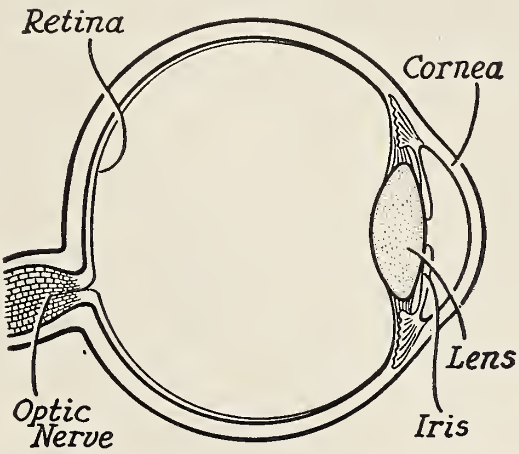

Fig. 49. The structure of the human eye

accommodation. When the eye views near-by objects, the lens is contracted to make it more convex; when the eye shifts to a distant object, the lens is relaxed and resumes its normal, resting form. Accommodation, then, is for purposes of looking at near-by things. The lens in the eye of a farsighted person (see Figure 50) is unable to focus properly on near-by objects. That of a nearsighted eye (see Figure 50) does not focus on distant objects when it is at rest. Moreover, it cannot be made to do so without eyeglasses, because accommodation only makes matters worse.

A pilot must be able to perceive distant objects, and he must also be able to see things that are close at hand, such as the gauges and instruments on the panel of his plane. Moreover, he is often called upon to shift his attention from one to the other with great speed, so that he is required not only to accommodate, but also to accommodate quickly. In addition, if looking at near-by objects causes eyestrain, the result may be headache and loss of efficiency. Consequently those who seek to be pilots [6] are carefully tested as to their ability to accommodate and are required to meet certain technical standards.

Color vision. Many people are at least partly *color-blind,* and

[6] Except private and student pilots.

some of them are not aware that this is the case. The most common form of color blindness is that in which the person cannot distinguish between different shades of red and green. Theoretically a totally color-blind person would see only grays, but total color blindness probably does not occur in any large percentage of the population. It has been estimated, however, that about 25 per cent of the people show some evidences of color blindness.

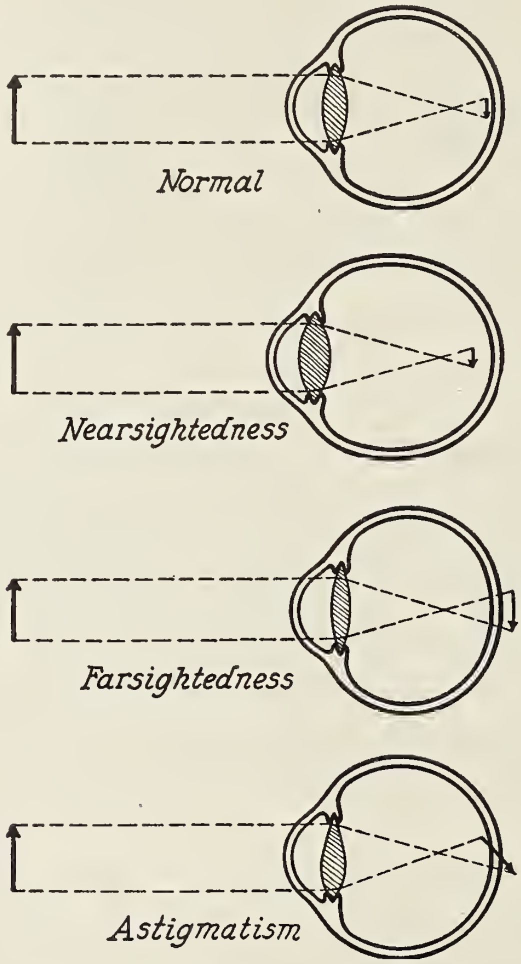

Fig. 50. The nature and causes of some eye defects

The inability to distinguish between reds and greens would be an obvious handicap to the airman. Like the operator of an automobile or the member of a train crew, he often has to deal with lights of such colors. In military work he may be called upon to recognize colored markings and to distinguish the green meadow far below from a reddish-brown plain or a marsh covered with vegetation. Good color vision is also of great importance if the pilot is forced to make an emergency landing.

It is easy enough to determine whether or not a given person is color-blind. This may be done among other ways by testing his ability to interpret color charts. One of these charts, for example, consists of circular areas made up of colored spheres. If the subject has normal vision, he will be able to read numbers (formed by some of the colored spheres) in the circular areas.

Color blindness disqualifies a candidate for service as a pilot in the Army or Navy and for airline or commercial pilot work. It is one of the vision defects that cannot be corrected through the use of eyeglasses or similar devices.

Depth perception. Another important faculty associated with vision is that of judging relative distances accurately. It depends upon what is known as *depth perception.* Some people can determine depth (or judge relative distances) very accurately, and others do not. Most of us are somewhere between these two extremes.

Reasonably good depth perception is necessary in the case of a pilot. It is particularly important in its relation to gauging the distance between an airplane and the ground in making landings, but it is also involved in a host of other decisions that the flier must make. It is another ability that can be tested, and arbitrary standards have been set up for various classes of pilots. These are highest for Army and Navy airmen.

Co-ordination of the eyes. Whether or not the eyes co-ordinate well also has to do with one's ability to judge relative distances. This is sometimes referred to as *ocular muscle balance.* Usually one eye is stronger than the other and acts as the sighting eye. If the muscles that move both eyes are properly co-ordinated, the weaker eye moves in harmony with the sighting eye. In the case of cross-eyes or similar defects, it is obvious that such harmony of movement is not achieved. Careful tests are given to detect cases in which eye muscles are not in balance. People who are found to be deficient in ocular muscle balance cannot obtain any kind of pilot license.

The eyes in general. The series of vision tests given to those who seek pilot training is too detailed and technical to be comprehensively treated here. The eyes are so important to safe flight that they are the subject of great concern and interest when it comes to the matter of selecting future pilots and crew members. Some of their defects can be corrected through the use of eyeglass lenses. Other failures of function cannot be overcome in such a manner and have to be regarded as disqualifying.

Hearing. You have already read something about the structure of the human ear (see page 62). We hear because air waves strike the eardrum, causing it to vibrate. The vibrations are carried through the middle ear by a series of three small bones: the hammer, the anvil, and the stirrup. Thus the vibrations are conveyed to the cochlea of the inner ear, in which the end organs [7] of hearing are located. An ear is a delicate structure, and such parts as the eardrum, the bones of the middle ear, and the parts of the inner ear may easily become temporarily or permanently injured.

Moreover, the ears of individuals are not equally good at birth. By the time a person has become mature, various defects may have developed in either or both of these organs. Often it will be found that the hearing of one ear is much more acute than that of the other. You can test yourself in a rather crude manner by holding a hand over one ear and moving a watch in from the side toward the other ear until the point is reached at which the ticking of the watch can be heard. Then the same test can be applied to the other ear. Sometimes marked disagreement between the two ears will be evidenced.

Pilots of the Army, Navy, and Civilian Pilot Training Program are given tests to assure that they can hear well with either ear. Briefly they are required to hear whispered numbers from a distance of twenty feet (either ear).[8] Other types of pilots take similar tests, but they do not have to meet such an exacting standard.[9]

Ability to hear well is needed by pilots, crew members, and even the ground personnel. At the present time most airplanes are equipped with radio, and almost everyone knows from his own experience how difficult it is to hear clearly when the reception is bad. Yet the safety of the plane in flight may depend

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[7] Nerve cells located along the basilar membrane, whose fibers extend to the brain.

[8] The standard, however, is not the same for all classes of military aviators.

[9] A private pilot, for instance, must hear the whispered words at a distance of three feet with at least one ear.

upon whether or not messages and other signals are received. A person with defective hearing might be handicapped even when radio reception was relatively good.

Another important use of hearing would probably not be guessed by those who have not flown. When air sweeps past the various surfaces of an airplane in flight, a swishing sound is produced. The experienced pilot knows this sound, and when it drops to a certain point he is aware that he no longer has safe flying speed. He will then use his motor to increase his speed or, if he is gliding, increase the angle of his descent and thus achieve the same purpose.

Balance, or equilibrium. The structures concerned in maintaining balance or equilibrium are the bones and the muscles, but they are "at the mercy" of various sensations. Some of these sensations (touch) originate in the joints, tendons, and muscles of the body, and some come from the eyes. Others are relayed to the brain by the vestibular apparatus of the ear (see page 98). If the central nervous system handles all such incoming messages in an efficient manner, appropriate responses will be sent out to the muscles of the body and balance will be maintained.

Good powers of balance have proved to be so important to fliers that all classes of pilots are disqualified if they fail to meet the accepted standard. Some medical tests now in use are quite technical and require special apparatus, but here is one test that any person can try. Blindfold the eyes, stand up, raise one foot off the floor, and try to stay balanced on the other foot for fifteen seconds.[10] It will be found that this is not as easy to do as it sounds. If you succeed on one foot, try the other.

Poor powers of balance are exhibited by the automobile driver whose car is often a little bit out of control in rounding curves. Likewise in many sports a lack of balance makes the performer appear awkward and ineffective. Much in the experience of a flier relates to balance. A pilot who has good equilibrium knows by the "feel of things" whether he is banking and turning in a controlled manner.

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[10] It is a good idea to have another person present who may catch you in case of a fall and to choose a spot where you will not fall against furniture or similar solid objects.

Muscular Co-ordination

Co-ordination. Balance and muscular co-ordination are closely related. To throw effectively, a baseball pitcher must have balance. In addition, many muscles of his body (including far more than the muscles of the arm and shoulder) must work together harmoniously if he is to throw the ball where he wants it to go. The harmonious working together of various body parts is known as co-ordination. We should note that it also makes demands upon the nervous system, because that system controls action of the muscles. Muscular co-ordination is usually good in the case of successful athletes.[11] It is also characteristic of the superior automobile driver and the successful airplane pilot.

Some very simple tests can show in a general way whether or not an individual has good co-ordination. One of them is to have the candidate attempt to bring the tips of his index fingers together, starting with the hands in front of the body and about a foot apart. Another is to have him shut his eyes and touch the tip of his nose with each index finger and the tips of his fingers (alternately) with his thumbs. Inability to do so indicates that muscular co-ordination is poor. A further simple experiment is to compare the abilities of several people to "walk a chalk line" at various speeds. Marked individual differences will probably be observed.

Tremor. It is easy to understand that the flier should have a steady hand. If the hand "shakes" even when a person tries to hold it still, it is an indication that *tremor* exists. As many people would say, the person does not have "steady nerves." A simple way to test for the existence of tremor is to have the subject try to raise a glass filled to the brim with water. Another is to have a subject extend his arms in front of the body, with the fingers spread apart and slightly bent. If the fingers show much evidence of tremor, the success of the subject as a pilot is questionable.

The muscles in general. Pretraining tests give some atten-

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[11] This is one case in which the successful athlete probably is at an advantage over the average person. It must be remembered, however, that some people who do not classify as athletes possess very good powers of co-ordination. Moreover, the person having good co-ordination may fail to meet other standards (see page 120).

tion to the general condition of the muscles. Various means are used to test their strength. They are also examined to see if any of them are abnormally large or atrophied to the extent that they are largely useless. Any marked abnormality will disqualify a candidate for the Army or Navy air services.

The Circulation

You have no doubt noticed that the circulatory system has been mentioned in several previous discussions. This indicates a fact—that the circulatory system is of first-rank importance in flight activities. A sound circulatory system is desirable if not requisite for many aviation experiences.

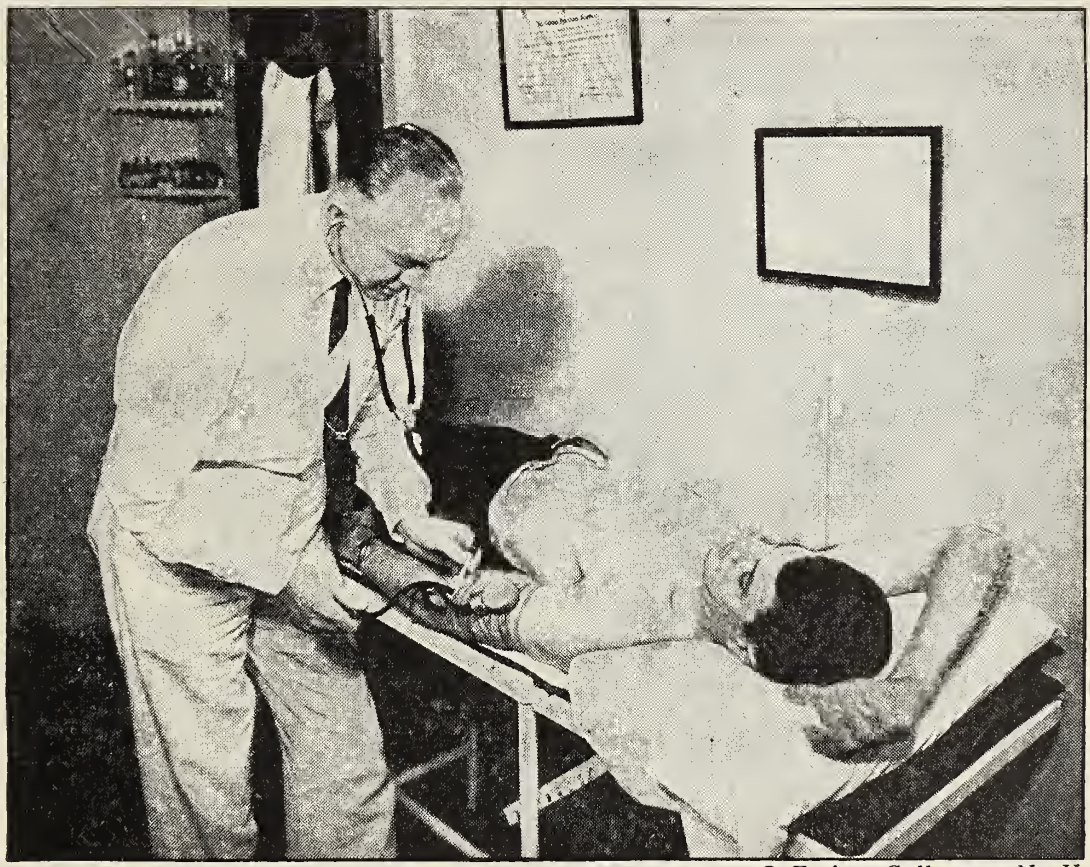

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Fig. 51. Apparatus for taking blood pressure applied to the upper arm

Blood pressure. One test often performed to check the efficiency of circulation[12] is to take a blood pressure reading. An elongated rubber sack is applied to the upper arm. Into it, as shown in Figure 51, air is forced by means of a rubber bulb

[12] An abnormal blood pressure may of course indicate that other organs of the body are not performing their functions properly.

until the flow of blood in the main artery of the upper arm is stopped. The scale (millimeters of mercury) is read at this point, and the figure represents what is called *systolic pressure.* Then air is allowed to escape from the sac until the flow of blood in the artery is resumed. At this point another reading is made, which represents the *diastolic pressure.*

The Army examination (for candidates for commission) requires that systolic pressure be no greater than 150 millimeters for candidates over twenty-five and 140 millimeters for men who are under that age. Diastolic pressure must not exceed 100 millimeters, and systolic pressure must not be less than 105 millimeters. Those who apply for actual flight training must exhibit a systolic pressure less than 135 millimeters and a diastolic pressure less than 90 millimeters.

We have of course noted (see page 90) that people having high blood pressure are less subject to the effects of acceleration, but there are many reasons why the condition of high or low blood pressure must be regarded as a warning sign.

The Schneider index. A Schneider index of +6 or better is required of Army, Navy, and airline pilots and those who are in the Civilian Pilot Training Program. This index[13] is determined by relating the results of several tests, some of which are relatively simple and will be mentioned here. One is to take the pulse rate when the subject is at rest.[14] Another is to take the systolic pressure while the subject is at rest and while standing. Further measurements include the pulse rate while one is standing, increase in pulse rate after moderate exercise, and the time it takes the pulse to return to normal after such exertion.

General Health

Most of the points mentioned in this chapter represent rather specific requirements that a flier should be able to meet. There are other matters of more general health, however, that are of great and obvious importance. Some of these, as in the

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[13] A good description of how to take a modified Schneider index will be found in the following source: Ray, E. L., and Washburn, S., *Are You Fit to Be a Pilot?* pp. 41–45; Wilfred Funk, Inc., New York, 1941.

[14] For the sake of example it may be indicated that the subject's rating is +3 if the pulse rate is between 50 and 70, +2 if it is between 71 and 80, +1 for a reading of 81 to 90, 0 for 91 to 100, −1 for 101 to 110.

case of the nervous system (see page 121), may be indicated by an individual's medical history. Others are revealed only upon medical examination. Some are temporary disabilities or are subject to correction; others present more serious problems and disqualify a candidate permanently.

Some temporary defects. In considering some defects that may be corrected, let us begin with the teeth. You have doubtless learned already the importance of dental hygiene; but you probably know that many people take indifferent care of their teeth, with the result that the latter are in rather poor condition even before maturity is reached. For military purposes this state of affairs is unsatisfactory. In a good many cases, however, it is not too late to make the necessary repairs. Similarly a good many infections that might be present and account for fevers at the time when candidates are first examined would be expected to disappear in due course of time, especially when proper treatment is given. There are, then, some defects and diseases that yield to correction or treatment and are not necessarily disqualifying except temporarily.

More important diseases and defects. Other ailments, on the other hand, are likely to be of more permanent nature. Syphilis, for example, disqualifies a candidate for admission to military flight service. Of course syphilis usually yields to proper treatment, particularly if it is begun early in the history of a case. Those who have had recent attacks of malaria are also disqualified by the military services. Sometimes months and even years of treatment may fail to rid the human body of malaria germs.

Some of the other things ordinarily assumed to disqualify for military work are a history of asthma or hay fever, an active case of tuberculosis, the existence of ulcers in the stomach or duodenum, various kinds of heart disease, chronic kidney disease, or failure in function of the ductless glands. In connection with the last named defect you may remember that failure of the pancreatic islands of Langerhans, for example, results in diabetes.

Summary

It is not to be assumed that all of the important factors involved in physical fitness for flight have been discussed in this chapter. They could not be in any event, because such factors are too numerous and some are too technical.

In general, however, it will be seen that the requisites are a normal body, one that is free from active infection. In addition, there are special requirements with respect to the nervous system, the eyes, the ears, the "sense" of balance, muscular coordination, and the circulatory system. Many of the standards that must be met would be desirable standards for other occupations. The particular combination that has been described here seems to be the one that fits the demands made by flight.

Some people might think that these flight standards or requirements are very difficult to meet, and that only a select few could possibly meet them. This is not the case. Actually a good many people can satisfy the physical demands set by the Army and Navy air services for pilot training. These services also make less exacting requirements of personnel in other aviation classifications. Physical standards established for pilots in nonmilitary occupations, moreover, are also lower in some instances, especially in the case of private pilots.

In other words, we must recognize that some military operations call for particularly good physical condition, because airmen must meet the more trying conditions that exist at the higher altitudes and must occasionally encounter the results of accelerations. Fliers in ordinary civilian services are not likely to have to deal with such difficult conditions.

8

AIR TRAVEL AND DISEASE CONTROL

NOW that growing mastery of the air has made the world a smaller place, we must change our thinking to meet the new conditions. Airplanes make long, swift journeys possible, as everyone knows. But they do something else, which is even more important from the standpoint of this discussion. They penetrate into regions where there have been no railroads and no highways, and many of these are places where deadly diseases lurk—diseases which have given us no great concern in the past but with which we must now reckon.

The so-called tropical diseases, for example, have not been commonly studied in our schools. They seemed far away, and they really were for most people who lived their lives in temperate zones. That, however, was in the world of yesterday. Now we face the fact that many men and women are flying to the tropics and will continue to fly there. Others will be returning from the warm countries, and some of them may bring germs and other parasites with them. There is even another danger if proper care is not taken. This is that airplanes may bring in insect pests from foreign lands, including some that attack crop plants and others that transmit germs.

Airplanes, Disease, and Insects

Early studies. Before going farther with this discussion, it is proper to give some thought to the question, "Are germs carried by the air?" That they might be is not a new idea by any means. Even the great student of germs Louis Pasteur made journeys to the Alps so that he could investigate whether or not bacteria were found well above sea level.

Of course there really were two problems to be solved. One was a matter of proving that germs were or were not found in the air. If the answer to this was no, the matter was settled. But, if the answer proved to be yes, it was necessary to find out if air-borne microbes were alive and could still cause trouble. No one can doubt the importance of these questions, and it is

Fig. 52. These are greatly enlarged drawings of bacteria and some animal parasites. All carry diseases and are properly called germs. In addition, the filtrable viruses are sometimes classified as germs, because they, too, cause diseases.

therefore surprising to find how little has really been done during the past sixty or seventy years by way of getting the answers.

Diseases caused by insect vectors. A number of diseases, such as malaria, are conveyed to man through the bites of mosquitoes. We call the insects that transmit them *vectors,* and we know that, if there were no vectors, they could not cause us to become ill. In the case of insect vectors it makes little difference whether or not the germs float about in the air. The first and most important concern is to avoid the insect vectors.

Other diseases. Other diseases, however, have nothing to do with the presence or absence of insects. The germs that cause them are known to enter our bodies by way of mouths and nasal passages and even in some cases to penetrate the skin layers. Some are found in what we eat and drink. Others are on utensils that we handle. But are any of them floating in the air about us?

Air-borne plant diseases. In some ways we know more about air-borne plant diseases than about those of our own bodies.

Many spores capable of causing plant diseases have been picked up in airplane collections. In fact, some of them have been found at 36,000 feet. Certain spores of stem rust are known to be carried hundreds of miles by the wind and to cause rust on wheat when they drop to the earth again. Not nearly as much is known about bacteria that cause plant diseases or about plant-attacking viruses. We may note, however, that such viruses are known to be carried by various insects, and that these insects are a part of the vast air population.

Air-borne human diseases. It has likewise been known for some time that microbes of some human diseases are found in the air, particularly in buildings or close to the ground. For a long time, however, it was thought that germ infections did not commonly reach us through the air. The results of recent studies, however, now cause us to doubt that this is the case. We have now learned (see Figure 2) that all people throw off droplets of moisture when they sneeze, talk, or even breathe. Germs are in such droplets, and when the moisture dries they become *droplet nuclei*. These droplet nuclei, with their germs, may remain in the air for some time.

Experiments have also shown that, if the air people breathe is irradiated, the spread of some diseases is checked. It would seem that the germs of these diseases are killed by the ultraviolet light. Such experiments of course have dealt with indoor conditions, and it might be argued that in the out-of-doors things would be different. Would not the ultraviolet rays of sunlight soon kill microbes? Perhaps they should, but, as indicated on page 4, this does not seem to happen in the case of many tiny plants and animals that float about in the air. When they are collected and taken into the laboratory, they often prove to be alive and form colonies on culture surfaces. Whether this is also true of germs that cause human diseases is not known at the present time.

Bacteria in the upper air. Not all germs are bacteria of course, but it is interesting to note that bacteria are common in the upper air. Both spore-forming and non-spore-forming types are well represented up to 10,000 feet. It was reported that twenty-nine different kinds of bacteria (largely spore-formers) were found at an altitude of 19,600 feet. Strangely enough, types known to cause human ailments do not appear to have been among these bacteria of the upper air, except for some streptococci.

More knowledge is needed. By this time you have probably come to the conclusion that what we know about this subject is rather fragmentary. It cannot be argued that this is untrue; but, on the other hand, some important facts have been learned. More studies are being made and must be made before all of the answers are known. In the meantime, we may tentatively conclude as follows:

1. Many microscopic organisms are found in the air, both near the earth and at high altitudes.

2. Organisms (spores) causing plant diseases are known to be air-borne in some cases.

3. Many tiny organisms of the upper air appear to survive conditions of light, temperature, and movement (see Chapter 1).

4. The spread of some human infections (indoors) appears to be checked by the use of ultraviolet light.

5. Germs (and viruses) of human disease probably are carried in droplet nuclei, which remain suspended in the air for long periods of time.

6. While most bacteria so far collected from the upper air have not been germs of human disease, some streptococci have been found.

The relation of our knowledge to air travel. Let us now consider what this knowledge (or lack of knowledge) means in terms of air travel. If it should be found that dangerous living microbes are common in the air, it might be necessary to take some special precautions, both when flying over certain territory and when landing at airports. We have long known the dangers of impure food and water and of utensils that bear germs. Visitors in the tropics are warned not to eat thin-skinned fruits unless they have been cooked first and not to drink water until it has been boiled or treated with suitable chemicals. Perhaps now we must add impure air to the list of things that must be guarded against.

Insect pests. Having touched briefly upon one phase of this subject, let us turn to another that has attracted somewhat more attention and study up to the present time. This is the certainty that insect pests will be scattered far and wide along air transportation routes unless steps are taken to prevent this disastrous occurrence.

There are two general reasons why we are concerned about these insects. Some of them are serious pests of agriculture. Others are well-known vectors of disease. It is appropriate to ask at this time why they are not spread over the surface of the earth in any event, by virtue of their own flight powers and by winds. The answer seems to be that, as indicated in Chapter 1, many species do tend to become widespread in distribution, but that many others are held in check by the great natural barriers, such as mountain ranges, oceans, and deserts.

Transportation of insect pests. It is also reasonable to ask if insect pests are not carried by ordinary ships and railroad trains. Of course the answer is yes. Insect pests and their eggs have been transported by such means again and again, and government agencies exist to prevent the importation of undesirable types. This is not easy to do, however, as will be indicated by the following example, which is only one of many examples that might be mentioned.

In 1916 the Japanese beetle first appeared at Riverton, New Jersey. It is not known to have any relationship to human disease, but it is a great pest to farmers and gardeners because it eats the green parts of many plants. How did it get to New Jersey? The answer seems to be that some beetle eggs were included with a shipment of plants that came from the Orient. The eggs hatched, and the young insects managed to establish themselves in the new land. Since 1916 the unwelcome invader has spread up and down the eastern states from Maine to the Carolinas and has become abundant in some localities. Thousands of dollars have been spent in efforts to find a successful means of control.

One may now inquire why the extension of air travel makes problems such as this one more complicated. In general, there are two reasons. First of all, we have learned how to safeguard shipments arriving by boat or by train, but we do not have this experience in the case of air transportation, although we are learning what to do. Second, there is the previously mentioned fact that air transportation reaches parts of the world with which there has been little or no direct traffic in the past. In these regions there are insects that attack crop plants and also insects that act as vectors of disease.

The possibility that insect pests might be carried by aircraft came to our attention in 1928 when the *Graf Zeppelin* arrived in the United States from Germany. Flowers carried by some of the passengers were examined and found to have on them moth eggs, aphids, and thrips among other things. Nothing of importance resulted from this incident, but more alarming discoveries were made later.

The malaria menace. Everyone has heard of malaria, but few are aware that this disease is one of the greatest threats to human security, especially in the warmer countries all over the world. It is transmitted to man by several varieties of female[1] *Anopheles* mosquitoes. In the human blood malaria

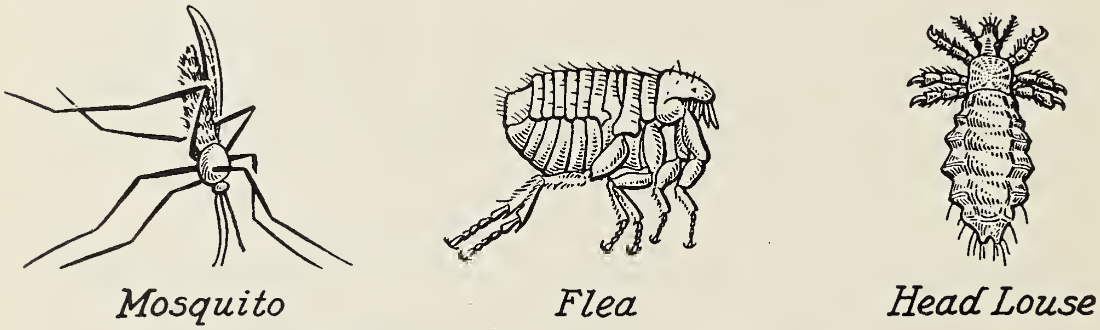

Fig. 53. Some important insect vectors

parasites (see Figure 52) enter red corpuscles. Here each parasite reproduces to form many more parasites; then the red corpuscles burst open and release the new parasites, together with a poisonous waste product called *melanin.* It is this melanin that causes the characteristic chill of malarial fever. In very bad cases destroyed blood cells and coloring matter from the liver give the urine a dark color. The victim is then said to have *blackwater fever.*

As you may know, there are three species of malaria parasites. They are all animal cells, belonging to the protozoan group:

Plasmodium malariae—chills every 72 hours
Plasmodium vivax—chills every 48 hours
Plasmodium falciparum—chills every 24 hours

[1] Apparently the adult males do not take food.

It is possible for a human victim to have any combination of these parasites in his blood stream. The drug quinine is commonly used to kill them, and so is a comparative newcomer among drugs, called *atabrine.*

Efforts have been made to control malaria by preventing the breeding of mosquitoes. Other measures include various ways of avoiding being bitten or keeping the number of bites at a minimum. People who must travel in malaria countries, including airplane crews, often take daily doses of from five to ten grains of quinine.[2] All measures taken up to the present time, however, have failed to stamp out the malaria menace in the world as a whole, and many tropical areas are veritable cesspools of infection.

Gambiae comes to Brazil. With the foregoing facts in mind, you can see why the sudden appearance of an African mosquito at Natal, Brazil, in 1930 caused great concern. This mosquito was *Anopheles gambiae,* a notorious vector of malaria. It was thought to have been brought across the ocean either by airplane (some experimental flights were being made at the time) or by some French destroyers traveling between West Africa and Brazil.

Whatever the facts may have been, serious outbreaks of malaria soon occurred in the Natal district. The death rate, moreover, proved to be high. This may be explained because strains of malaria parasites from different parts of the world are not all alike. Perhaps the people of Natal had low resistance to the strain brought in by the African mosquitoes.

In the years that followed an active campaign was waged against *A. gambiae.* The Rockefeller Foundation and the Brazilian government budgeted about two and a quarter million dollars for this work in the period 1939–1941. Recent indications are not only that *A. gambiae* is under good control, but also that the battle to wipe it out in the Natal district may be substantially won.

The yellow fever vectors. Meanwhile there has been no little concern about the yellow fever problem. Yellow fever of various types is present all the time in large areas of Africa and South America. In times past there have been outbreaks in

[2] Quinine, however, does not kill malaria sporozoites and therefore cannot be relied upon to prevent infection.

our own North America, and the disease is still represented in the West Indies, Mexico, and Central America. The scientist Noguchi claimed that it was a bacterial disease, but he was in error. Actually it appears to be caused by a virus.

Another mistake of the past was the belief that yellow fever is transmitted to man only by one species of mosquito, *Aëdes aegypti.* It is now known that this is far from being the fact. The vectors of jungle yellow fever, for instance, are mosquitoes *other* than *A. aegypti.* It has been stated that thirty-two species of *Aëdes, Culex, Mansonia,* and *Anopheles* (all mosquitoes) are vectors, and that certain flies, bedbugs, and ticks are mechanical carriers of the virus. Other research studies indicate that about seventeen insect species and three ticks can transmit yellow fever by bite, and that other insects, ticks, and certain small animals retain the virus in their bodies for various periods of time. That the conclusions are not in exact agreement is partly due to the fact that they were made at different times. They do clearly show, however, that the dangers of importing insect vectors of yellow fever is not limited to the species *A. aegypti.*

Recent studies have also made it evident that many different jungle animals are subject to yellow fever. Chief among them seem to be various types of monkeys. Hence sources of infection exist in far-flung tropical areas, even where men are few and far between. A visitor to such a jungle area may readily contract the disease and perhaps bring it back to a city or town, where an epidemic may be started.

However, yellow fever has never yet become widespread and common in the highly populated countries of the world. If it did, we should have a major disaster, because deaths in epidemics may range from 15 per cent to 85 per cent. With such a possibility in mind, the International Sanitary Convention for Aerial Navigation in 1933 vested authority for suitable precautions in the officials of countries through which airplanes pass. Previously (in 1930) the United States had announced quarantine regulations for airplanes, for the purpose of controlling yellow fever.

Dengue fever. It is fitting also that some mention be made of dengue, or breakbone fever, because the virus of this disease is conveyed to man by *Aëdes aegypti* and also by the oriental mosquito *A. albopictus*. As in the case of yellow fever, monkeys are known to carry the disease.

Dengue is not greatly feared because it usually does not result in death. However, its human victims are made most uncomfortable and become unfit for work for a greater or less period of time.[3] It is true that they develop a sort of partial and temporary immunity after an attack, but this is small consolation. The disease is represented in the warm countries of the world and sometimes becomes epidemic. There have been recent outbreaks in our own South.

Bubonic plague. So that you will not get the idea that the only important insect vectors of disease are mosquitoes, let us now give a little thought to the case of bubonic plague. The great epidemics that prostrated Europe during medieval times give us an indication of what the plague can mean when it becomes epidemic. It is caused by a bacterium (plague bacillus), and it is transmitted to man by rat fleas. House rats and various other rodents, including ground squirrels, marmots, chipmunks, and others are subject to the plague.[4] The disease is now found mainly in the Orient, southern Asia, Africa, and parts of South America. Local outbreaks have occurred in various parts of our own Far West since 1900, and western rodents are known to be infected at the present time,[5] although human cases have not been common in recent years.

The type of plague conveyed to man from rodents other than rats is called *sylvatic*. It does not appear to be much of a menace in itself. As one authority points out, however, fleas can transmit it from squirrels to rats. Then, if rat fleas transmit it from rats to man, we are confronted with the type of black death that is so justly feared. Deaths in times of epidemics have run as high as 90 per cent although it must be admitted that a means of making people immune[6] is now available.

Other possibilities of future outbreaks of the disease in

[3] For this reason the disease is likely to be a military problem when troops remain in tropical areas. No effective vaccine is available.

[4] Apparently it is transmitted among these types by various species of fleas.

[5] This infection of rodents has been reported as far east as North Dakota and New Mexico.

[6] A preventive inoculation.

North America depend upon whether or not infected rats and fleas reach our shores. Ways and means of preventing their coming in cargo ships were worked out long ago, but now air transport brings some of the plague spots of the world far closer to us. Rat fleas might be carried by airplanes, and rats have actually been observed taking refuge in large aircraft.

Typhus fever. Another important illness transmitted by insects is typhus fever, which in different epidemics has been known to kill from 15 per cent to 50 per cent of its victims. It is represented in parts of European Russia and Asia all the time. This variety of disease is conveyed to human victims by lice. The principal New World centers of infection have been Mexico and since about 1915 our own South and Southwest. Here the disease takes a somewhat different form, existing among house rats and being transmitted to man by fleas and other parasites. Sometimes called *murine typhus,*[7] it has been on the increase in the United States during recent years. The old epidemic form of typhus fever, however, has not been unknown in the New World. Before the middle of the last century it swept cities along our Atlantic and Gulf coasts.

African sleeping sickness. In the consideration of diseases that might become more widespread because of air travel, some mention should be made of African sleeping sickness, which has been largely confined to the so-called Dark Continent. It is caused by an animal parasite known as a trypanosome and is transmitted to man by two or more species of tsetse flies. Perhaps other biting flies also convey the disease among different wild animals and even among men. Be that as it may, infected insect vectors of this dreaded killer would be a menace if carried to the more populous centers. In at least one case a vector has already been found on an airplane.

Insects and disease. All the insects that act as vectors of disease have by no means been mentioned in this account. In addition, there are many species that act merely as mechanical agents in carrying germs to man. Thus the common housefly does not bite us, but it carries microbes, including those of typhoid fever, to the things that we eat and drink. It may, then,

[7] A Mexican variety of the disease is called *tabardillo.* A milder form encountered in the United States is known as Brill's disease. Rocky Mountain spotted fever (also known as tick fever) seems to be closely related.

be repeated that the potentially dangerous insects are not only the mosquitoes, but many other types as well.

Insects carried by airplanes. For some years now various efforts have been made to prevent the transportation of insects by airplanes. Despite standard precautions[8] various living insects were found on seaplanes arriving at Miami, Florida, from South America, Mexico, and Central America in 1938. During the year 398 airplanes were inspected and 187 of them contained insects. The total number of insects found was 651, of

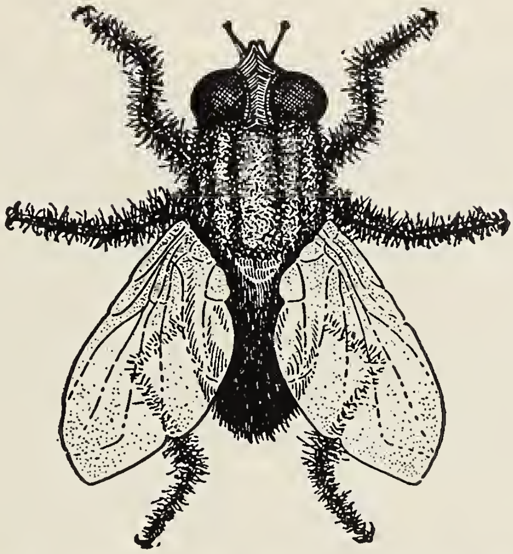

Fig. 54. The housefly, another notorious carrier of germs. It does not bite us, but it carries germs to what we eat and drink.

which 166 were alive. Among the more common types were houseflies, several kinds of mosquitoes, midges, gnats, and other small flies. There were also some beetles, wasps, ants, moths, cockroaches, and chinch bugs. Two live spiders were discovered.

From this investigation we can see that the method followed in spraying the aircraft (see footnote 8) was not entirely satisfactory. A fairly large number of the insects were not killed within a period of about a half hour. Another conclusion may be that insects, including vectors of disease and pests of agriculture, are likely to be found in airplanes.

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[8] Airline employees used a small hand-pump gun to spray a pyrethrum compound a half hour before each plane came into port. While this was going on, the plane's ventilators were closed and remained that way for ten minutes after the spraying was completed. On overnight stops the empty planes were sprayed and closed up for the night.

Other studies have indicated that most or all of these insects get in airplanes while the latter are on the ground. Insects are not likely to be picked up on the *outside* of an aircraft while it is in flight. The reason for this is that modern streamlining has left no places on the outer surface that are sheltered from wind stream and to which insects might cling with reasonable security.

Another study was made of insects collected from airplanes at the Khartoum (Africa) airport during the period from July, 1935, to August, 1938. Over 2000 aircraft were examined, and nearly 3000 insects were found. They represented 146 different species. The most common types were houseflies, although many other varieties had possible relationships to disease.

Apparently insects may enter through windows and hatches when an airplane is on the ground and also via the ventilation system.[9] It has been shown that some of them (mosquitoes) survive altitudes of 10,000 feet and trips covering 10,000 miles and lasting six or seven days. Most sprays now being used to kill them have a pyrethrum [10] base. In reporting on certain experiments made to determine whether a pyrethrum spray would kill mosquitoes, the investigators concluded that it would if properly used.

For the control of insects in transport airplanes there is recommended a system of power spraying that can be operated in flight by the ship's pilot. It should be used just after leaving port and for a half hour before alighting again. Smaller civil or military craft could be put in fumigation chambers or treated with portable fumigating or spraying machines. There does not seem to be much hope of keeping airports free of insects, although this would serve to keep the pests out of aircraft.

Airplanes as insect destroyers. It is interesting to note that we use airplanes in our never-ending war against insect pests. Planes capable of relatively slow flight close to the ground are often employed to spread poison dust over large fields. The dust settles upon the crop plants and the ground and kills

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[9] They are not likely to enter the air ducts during flight at speeds over 100 miles per hour.

[10] Pyrethrum is an alkaloid poison obtained from the flowers of the pyrethrum plant. It acts upon the nerves and muscles.

many insect pests. In recent years airplanes have also served to control mosquitoes in vast swampy areas of the South. Merely draining such swamps is not always a possible or satisfactory way to solve the problem. Dusting them with Paris green seems to be a better and more economical method in some cases.

Experiments have been reported on the use of airplanes to spread a mixture of Paris green (20 per cent by volume) and powdered soapstone over swampy lands where malaria mosquitoes bred in great numbers. Dust was placed in a special hopper and driven out through a vent that opened below the

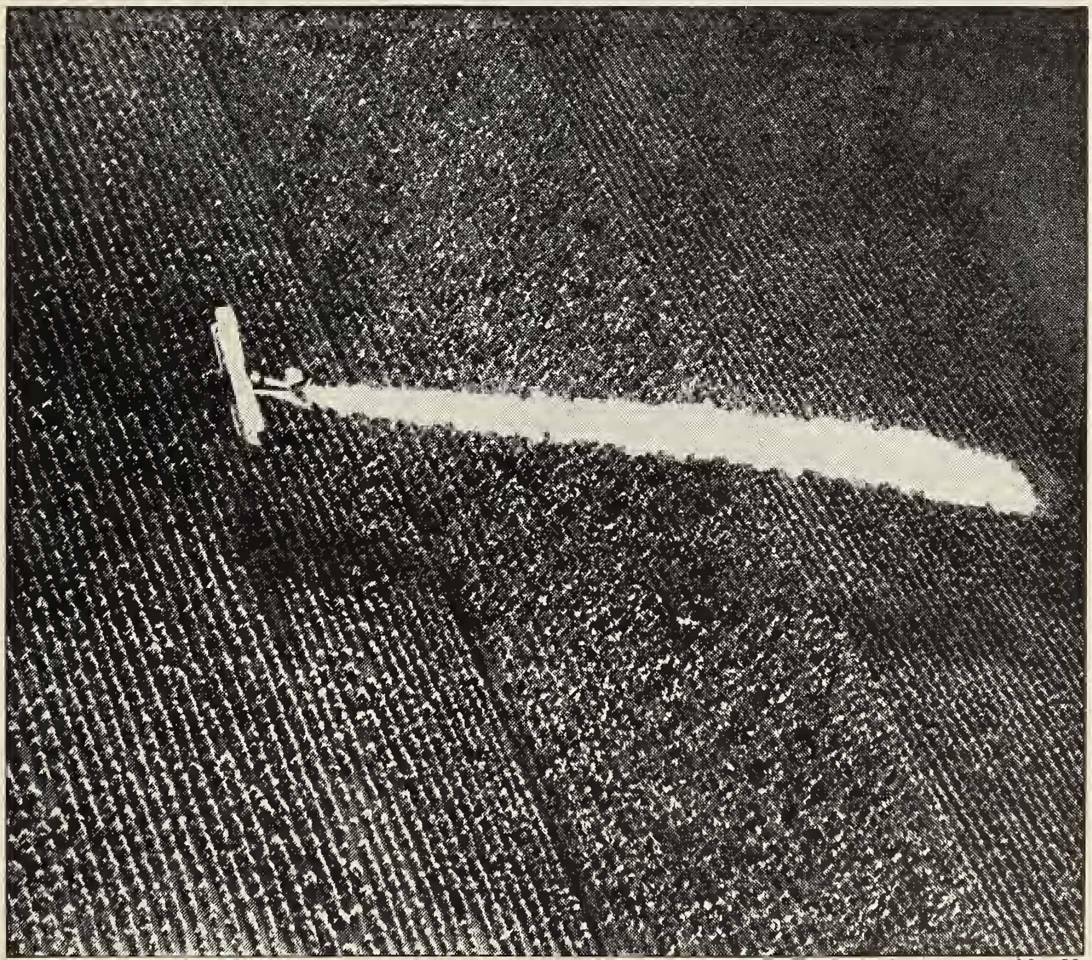

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Fig. 55. Airplane spreading poison dust over a field

fuselage. About one pound of dust per acre was used, and it proved to kill mosquito larvae in a satisfactory manner where the waters were not covered by too much vegetation.[11] The cost was about 37 cents per acre.

[11] Where vegetation grew up to cover the water, the method used was about 70 per cent effective.

Airplanes and Infected People

Men may also carry disease. The possible relation of air transportation to disease is not confined to insect vectors that might be carried from one part of the earth to another. As has been noted before, some diseases are not spread by such vectors, but by contact or near contact of one person with another. The microbes of other diseases are likely to enter our bodies with food and drink. There are obvious ways in which aircraft may hasten the spread of such illnesses, because men also carry the germs. If an infected person is flown from Africa to some town in North America, the result may be an epidemic.

Malaria and yellow fever again. Man may sometimes carry diseases that are transmitted by vectors. Suppose, for example, that John Doe gets jungle fever in South America or some African strain of malaria. He comes back to North America uncured, and vectors of the disease he has contracted bite him. They get the virus (yellow fever) or the malaria germs from John Doe, and in a short time they are able to infect other people. This sort of thing is known to have happened in the past. In these days of world-wide air travel, there is every chance that epidemics will be started in many places where otherwise they might not be expected to occur.

In the case of diseases that are conveyed to man by vectors, then, we can see two obvious dangers. The first danger arises when vectors (infected with germs or viruses) are brought into a region. The second arises when infected people are similarly transported to a place where vectors of the disease in question exist. With this latter hazard in mind, some airlines have had all of their flying personnel made immune to yellow fever, for which an apparently effective vaccine is now available. Unfortunately no means of making people immune to malaria is now known, although research progress along such lines has been reported.

Asiatic cholera. Let us now consider another disease that is conveyed to man through food and liquids. It is Asiatic cholera, caused by a spirillum.[12] No vectors are involved in its transmission; in fact, animals other than man are not known to be affected. Man, however, seems to be an easy victim, and

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[12] A type of bacterium that is elongated and spiral in form.

in some epidemics about 80 per cent of those who became ill died. In times past cholera has been widespread in distribution, and the United States has not escaped.[13] At the moment the disease is represented by scattered cases in southern Asia and India.

Now suppose that John Doe becomes infected with cholera while in India. He might even have some of the germs in his body and not be aware of the fact because symptoms of the disease had not yet developed. If he is now taken back to North America via airplane and allowed to lose himself in some city or town, his condition might not come to the attention of a doctor right away. Meanwhile, if strict sanitary measures were not observed, food and water might be contaminated and other people would soon be victims of the malady. In other words, an epidemic might be started.

Of course the series of events described here are not likely to occur, because safeguards can and will be observed. John Doe, showing symptoms of illness would not be allowed to board an air transport. If symptoms did not develop until he was en route, he would promptly be placed under some sort of quarantine, so that necessary sanitary measures would be taken. If an epidemic did get started, it could be checked, because a cholera vaccine is available even though it confers protection for only a few months. In fact, John Doe could probably avoid any trouble in the first place by taking the immunity treatment before venturing into a region where cholera is known to exist.

Dysentery. Similar dangers exist in the case of another food- and water-borne disease known as bacillary dysentery.[14] As the name would indicate, it is caused by bacteria of the bacillus type. This dysentery, which is common throughout the tropics, leads to much disability. Local outbreaks have occurred in the United States from time to time, usually traceable to people who had entered from tropical countries.

With rapid air transport providing a means of carrying people all over the world, the possibility of spreading this disease into many regions that have been free from it exists. Actual

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[13] The last United States epidemic occurred in 1892.

[14] There is another type of dysentery, known as amoebic dysentery, which is caused by an animal parasite (Endamoeba).

dangers to life are not so great as in some other cases previously mentioned, although fatal cases of dysentery are by no means unknown. Obvious safeguards are to insist upon pure food and drink and to isolate victims of the malady until there is reasonable assurance that they are free from germs.

Summary

In the foregoing discussion we have seen that a world system of air transport brings more and more people to the remote corners of the earth. Here they encounter microbes and other parasites with which they are largely unfamiliar. In some cases they can be made immune to specific diseases before they begin their journeys, but protection against other maladies cannot be conferred. It is necessary therefore that such people be educated as to the dangers. They must learn to be wary of insect vectors and of germs in food and liquids. It may even be found that dangerous germs are in the air that they breathe. Only by knowing the dangers and avoiding them can air travelers be made reasonably safe.

We have also noted that insect vectors of disease and agricultural pests are almost certain to be spread far and wide through the agency of air transportation unless special measures are taken to forestall such a result. We can also see the possibility that infected people may be carried from one locality to another so rapidly that in some cases they will not have time to develop symptoms of their diseases.

It is evident that ways and means must be found to overcome the dangers described here. There appear to be two general needs. One of them is an effective means of spraying or fumigating airplanes so that all insects and similar small forms of life will be killed. Another is some system of examination (and isolation when necessary) to make certain that people infected with dangerous diseases are not carried to many different localities and turned loose among the general population, where they can be the source of epidemics.

The problems raised by air transportation differ only in degree and detail from problems that are age-old. The Roman armies had their troubles of like nature, and so did the towns and villages that these foot soldiers passed through on their laborious marches. The white explorers brought unknown discases to the natives of North and South America and perhaps carried back a few New World infections with them.

The danger that insect vectors and infected rats, people, and even pets will be transported by ship or railroad has long been recognized and partly offset by a variety of regulations, inspections, and quarantines. So it would seem that the new challenge raised by air transportation is one that we should be able to meet. Old methods will have to be adapted to the new conditions. Some new methods have been devised and will no doubt be improved upon. Meanwhile one of our best defenses is knowledge of the dangers, so that we may recognize and avoid them. This should enable us to come safely through a period of adjustment to the time when air transportation will extend without danger from disease to all parts of the world.

SELECTED REFERENCES

Allen, A. A., *The Book of Bird Life;* D. Van Nostrand Company, New York, 1930

Armstrong, H. G., *Principles and Practices of Aviation Medicine;* The Williams and Wilkins Company, Baltimore, 1939

Aymar, G. C., *Bird Flight;* Dodd, Mead and Company, New York, 1935

Baughman, Harold E., *Baughman's Aviation Dictionary and Reference Guide;* Aero Publications, Glendale, California, 1942

Carlson, A. J., and Johnson, V., *The Machinery of the Body,* Second Edition; University of Chicago Press, Chicago, 1941

Chandler, A. C., "Yellow Fever, Plague and Typhus—Smoldering Threats," *The American Biology Teacher,* Vol. 4, No. 7, pp. 199–202, 1942

Dill, D. B., *Life, Heat, and Altitude;* Harvard University Press, Cambridge, 1938

Diringshofen, H. von, *Medical Guide for Flying Personnel* (translation by V. E. Henderson); University of Toronto Press, Toronto, Canada, 1940

Fitzpatrick, F. L., *The Control of Organisms;* Bureau of Publications, Teachers College, Columbia University, New York, 1940

Fosdick, R. B., *The Rockefeller Foundation Annual Report;* The Rockefeller Foundation, New York, 1940

——, *The Rockefeller Foundation: A Review for 1941;* The Rockefeller Foundation, New York, 1942

Gemmill, C., *Physiology of Aviation;* Charles C. Thomas, Springfield, Illinois, 1942

Gillmer, T. C., and Nietsch, Erich, *Simplified Theory of Flight;* D. Van Nostrand Company, New York, 1941

Griffitts, T. H. D., "Air Traffic in Relation to Public Health," *American Journal of Tropical Medicine,* Vol. 13, pp. 283–290, 1933

——, and Griffitts, J. J., "Mosquitoes Transported by Airplane. Staining Methods Used in Determining Their Importation," *Public Health Reports,* Vol. 46, pp. 2775–2782, 1931

Grow, M. C., and Armstrong, H. G., *Fit to Fly;* D. Appleton-Century Company, New York, 1941

Haggard, H. W., *The Science of Health and Disease;* Harper and Brothers, New York, 1938

Henderson, Yandell, *Adventures in Respiration;* The Williams and Wilkins Company, Baltimore, 1938

Hoff, E. C., and Fulton, J. F., *A Bibliography of Aviation Medicine;* Charles C. Thomas, Springfield, Illinois, 1942

Jordanoff, Assen, *Safety in Flight;* Wilfred Funk, Inc., New York, 1940

Liljencrantz, E., *The Use of the Eyes at Night;* Navy Department, Bureau of Medicine and Surgery, Night Vision Board, 1942

Mackie, F. P., and Crabtree, H. S., "Destruction of Mosquitoes in Aircraft," *Lancet,* Vol. 2, pp. 447–450, 1938

Peckham, Betty, *Sky Hostess;* Thomas Nelson and Sons, New York, 1941

Proctor, B. E., "The Microbiology of the Upper Air. I," *Proceedings of the American Academy of Arts and Sciences,* Vol. 64, pp. 315–340, 1929

Ray, E. L., and Washburn, S., *Are You Fit to Be a Pilot?* Wilfred Funk, Inc., New York, 1941

Rowan, William, *The Riddle of Migration;* The Williams and Wilkins Company, Baltimore, 1931

Schlotthauer, H. L., "Aircraft as Disease Carriers," *California and Western Medicine.* Vol. 53, p. 33, 1940

Simmons, J. S., "United States Army's War in Air Against Mosquito-borne Diseases," *American Journal of the Medical Sciences,* Vol. 106, N. S., pp. 153–167, 1938

Stakman, E. C. (Ed.), *Aerobiology;* American Association for the Advancement of Science, Washington, D. C., 1942

——, Popham, W. L., and Cassell, R. C., "Observations on Stem Rust Epidemiology in Mexico," *American Journal of Botany,* Vol. 27, pp. 90–99, 1940

Thomson, J. A., *The Biology of Birds;* The Macmillan Company, New York, 1923

U. S. Office of Chief of Air Corps, *Physiological Aspects of Flying and Maintenance of Physical Fitness;* War Department, Technical Manual, TM 1–705, Government Printing Office, Washington, D. C., 1941

U. S. Surgeon-General's Office, *Notes on Cardiology in Aviation Medicine;* War Department, Technical Manual, TM 8–305, Government Printing Office, Washington, D. C., 1940

——, *Notes on Eye, Ear, Nose and Throat in Aviation Medicine;* War Department, Technical Manual, TM 8–300, Government Printing Office, Washington, D. C., 1940

——, *Notes on Physiology in Aviation Medicine;* War Department, Technical Manual, TM 8–310, Government Printing Office, Washington, D. C., 1940

——, *Notes on Psychology and Personality Studies in Aviation Medicine;* War Department, Technical Manual, TM 8–320, Government Printing Office, Washington, D. C., 1941

——, *Outline of Neuropsychiatry in Aviation Medicine;* War Department, Technical Manual, TM 8–325, Government Printing Office, Washington, D. C., 1940

U. S. War Department, *Standards of Physical Examination for Flying;* Medical Department, A. R. 40–100 (1–2), Government Printing Office, Washington, D. C., 1940

Van Liere, E. J., *Anoxia: Its Effects on the Body;* University of Chicago Press, Chicago, 1942

Watson, R. B., and others, "The Role of Airplane Dusting in the

Control of Anopheles Breeding Associated with Impounded Waters," *Public Health Reports,* Vol. 53, pp. 251–263, 1938

Welch, E. V., "Insects Found on Aircraft at Miami, Florida, in 1938," *Public Health Reports,* Vol. 54, pp. 561–566, 1939

Wells, W. F., "Viability of Bacteria in Air," *Science,* Vol. 79, p. 110, 1934a

Wenstrom, W. H., *Weather and the Ocean of Air;* Houghton Mifflin Company, Boston, 1942

Whitfield, F. G. S., "Air Transport, Insects and Disease," *Bulletin of Entomological Research,* Vol. 30, pp. 365–442, 1939

——, "Insects in Aircraft," *Nature* (London), Vol. 144, p. 158, 1939

MAGAZINES

Bulletin of War Medicine, British Library of Information, New York City

The Journal of Aviation Medicine, The Bruce Publishing Company, Milwaukee

War Medicine, American Medical Association, Chicago

SELECTED MOTION PICTURES

Air Currents and How They Behave, Pathé News. Sound; 12 min; 16 mm. (Sale: $27. Rent: $1.50—Gut,[1] B&H, Cine, IdP, VES, YMCA) Excellent diagrams. Photography and sound fair.

Part I. Clarence Chamberlin explains device for observing and photographing air currents. Obstacles are suspended in the wind tunnel to show the action of air currents flowing past surfaces with different shapes. Miniature airplane wing in tunnel illustrates forces that keep an airplane in the air and cause a plane to stall and go into a tail spin.

Part II. Norman Bel Geddes demonstrates how knowledge of aerodynamics can be applied to the streamlining of ships.

America Learns to Fly, National Dairy Council. Sound; 10 min; 16 mm. (Loan—BurH, NDC, YMCA) Photography, sound, and commentary good.

Birds on the Wing, Edited Pictures System. Silent; 12 min; 16 mm. (Rent—EPS) Photography good; excellent slow motion scenes.

The film illustrates (with slow motion) and explains the methods of flight exhibited by pigeons, gulls, owls, condors, and hawks.

Bray Aviation Series: Methods of Flight, Bray Pictures Corporation. Sound; 25 min; 16 mm. (Rent—Bray) Photography good. Excellent slow motion scenes of bird flights.

The film shows how man has attempted to copy the methods of bird flight. Slow motion studies illustrate how birds move their wing and tail feathers in flight and upon landing. Man's attempt to copy flapping wing flight shown by the flying ornithopter. Soaring and gliding birds are shown, with scenes of man's more successful imitation, the sailplane. Lighter-than-air balloons are shown, and examples of aircraft built on the rotating wing principle of the maple seed and the boomerang: the autogiro and the helicopter.

Champion Air Hoppers, Paramount Pictures. Sound; 15 min; 16 mm. (Rent—Films Inc.) Photography and sound excellent.

"Champion air hoppers" are gliding and soaring experts, whose feats are illustrated by this film. Pictures of crude homemade gliders and 1000-pound sailplanes show various methods of taking off, gaining altitude, looping, and landing as the commentary explains gliding and soaring, describes suitable weather conditions, and lists some of the records set by "air hoppers." Scenes taken from a glider in the air give an excellent impression of the sensations accompanying this type of flight.

Conquest of the Air, Films Incorporated. Sound; 45 min; 16 mm. (Rent—Films Inc. $10. TexVE, Wis) Photography, commentary,

[1] See list of distributors appended, page 155.

and sound good. Old photographs, drawings, and models of early aircraft used.

A documented account of the development of lighter-than-air and heavier-than-air craft from the first hot-air balloon and the drawings of Leonardo da Vinci to the airship *Hindenburg* and the clippers of today. A brief section explains, with diagrams, the basic principles of aerodynamics, while further sequences illustrate how science and research have contributed to man's conquest of the air.

Eyes of the Navy, Metro-Goldwyn Mayer, in co-operation with the United States Navy. Sound; 20 min; 16 mm. (Sale—apply TFC Loan—NavRec) Photography and sound excellent.

Illustrates the training of Navy air pilots, stressing the importance of these young men to the safety of our country. It includes scenes of Pensacola Air Training Station, living conditions and recreation of the cadets, ground school training, gunnery practice, actual flight instruction, instrument flying practice, graduation exercises, activities at San Diego Naval Air Station, advanced flight training, landing on airplane carrier, power diving, and scenes showing the extent of the operations of the Naval air arm.

Fighter Pilot, British Movietone News. Sound; 10 min; 16 mm. (Loan—BritLib) Photography and commentary good.

Three types of material are shown in the brief ten minutes of this film. Some of the instruments used in fighter planes are identified and their use is explained. A fighter pilot prepares to take off by putting on his "kit," consisting of inflated jacket, parachute, radiotelephone, and oxygen mask.

Principles of Flight, Eastman Kodak Company. Silent; 15 min; 16 mm. (Sale—Eastman $24. Rent—A&B, Gut, IoS, Ohio, Wis) Photography and diagrams good.

The film demonstrates, with scenes of gliders and kites, how air currents provide the "lift" forces that keep an airplane in the air. It explains, with diagrams, how streamlining cuts down the forces of resistance and how, by operation of the plane's controls (rudder, elevators, ailerons, and stabilizer fin), movements of a plane in flight are regulated.

Navy Wings of Gold, Pathé News. Sound; 30 min; 16 mm. (Loan—NavRec) Photography and sound excellent.

Illustrates the training activities of a naval aviation cadet at Pensacola, Florida. Ground school instruction, elementary flight, and advanced aerobatic training are shown and described by the commentator.

Sail Plane. J. and J. Love. Sound; 12 min; 16 mm. (Sale—$75. Rent—$3. Love) Exceptionally beautiful color photography. Commentary good.

The film shows the materials out of which sailplanes are made and gives general instructions for their construction. Sailplanes are shown in the air over the California coast. How pilots regulate the controls and ride the thermal and contour air currents is explained in some detail. The commentary stresses the fact that much about airplane flight can be learned from sailplanes.

Seed Dispersal, Erpi Classroom Films. Sound; 15 min; 16 mm; 35 mm. (Sale—16 mm. $50; 35 mm. $100. Erpi) Photography and commentary excellent. Remarkable effects from use of time-lapse camera.

How various types of seeds are disseminated by wind, animals, and natural propulsion is illustrated with time-lapse scenes showing how the seeds move about, germinate, and sprout.

Sky Defenders, Bell and Howell. Sound; 45 min; 16 mm. black and white, color. (Sale—b&w., $160; clr., $240. Rent—b&w., $10; clr., $20. B&H) Color photography, commentary, and sound good.

Illustrates the training of Army Air Corps Cadets. Recruits are shown at accredited schools of aeronautics before reporting as cadets at Randolph Field, Texas, where they undergo rigid physical examinations, receive ground school and elementary flight instruction, training in formation flying and aerobatics. Upon graduation from Randolph Field they report at Kelly Field for advanced military flight experience: instrument flying practice, gunnery practice, and specialized training with bombers, fighters, and observer planes.

Youth Takes to Wings, Bray Pictures Corp. Sound; 40 min; 16 mm. (Sale—apply Bray. Rent—$10. Bray) Photography and sound good.

The film shows how youths of today are learning the fundamental principles of flight through model airplane activities and how they are contributing to the study of aerodynamics. Pictures of birds in flight and models of other flying objects show the examples from which man designed the ornithopter, the autogiro, the helicopter, the glider, and the lighter-than-air balloon. The film touches on design of planes and explains, through scenes of planes of various types, why those used for different purposes are of different designs. The three parts of the Bray Aviation Series are included in this film.

List of Film Distributors

A&B	Akin and Bagshaw, Inc. 1425 Williams Street Denver, Colorado
B&H	Bell and Howell Filmosound Library 1801–1815 Larchmont Avenue, Chicago, Illinois 30 Rockefeller Plaza, New York, New York 716 North La Brea Avenue, Hollywood, California
BraF	Brandon Films, Inc. 1600 Broadway New York, New York
Bray	Bray Pictures Corporation 729 Seventh Avenue New York, New York

BritLib	British Library of Information 30 Rockefeller Plaza New York, New York
BurH	Burton Holmes Films Library Department 7510 North Ashland Avenue Chicago, Illinois
Cine	Cinema, Inc. 234 Clarendon Street Boston, Massachusetts
EPS	Edited Pictures System 330 West 42 Street New York, New York
Erpi	Erpi Classroom Films, Inc. 1841 Broadway New York, New York
Films Inc.	Films Incorporated 330 West 42 Street New York, New York
Gut	Walter O. Gutlohn, Inc. 25 West 45 Street New York, New York
IdP	Ideal Pictures Corporation 28–34 East 8th Street Chicago, Illinois
IoS	Iowa State College of Agriculture and Mechanic Arts Visual Instruction Service Ames, Iowa
Love	J. and J. Love Box 59, Chatsworth Los Angeles, California
NavRec	Apply at nearest United States Navy recruiting station.
NDC	National Dairy Council 111 North Canal Street Chicago, Illinois
Ohio	State of Ohio Department of Education Columbus, Ohio
TexVE	Texas Visual Education Company 305 West 10 Street Austin, Texas
TFC	Teaching Film Custodians 23 West 43 Street New York, New York

VES Visual Education Service
131 Clarendon Street
Boston, Massachusetts

Wis University of Wisconsin
Madison, Wisconsin

YMCA Motion Picture Bureau
Young Men's Christian Association
347 Madison Avenue, New York, New York
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